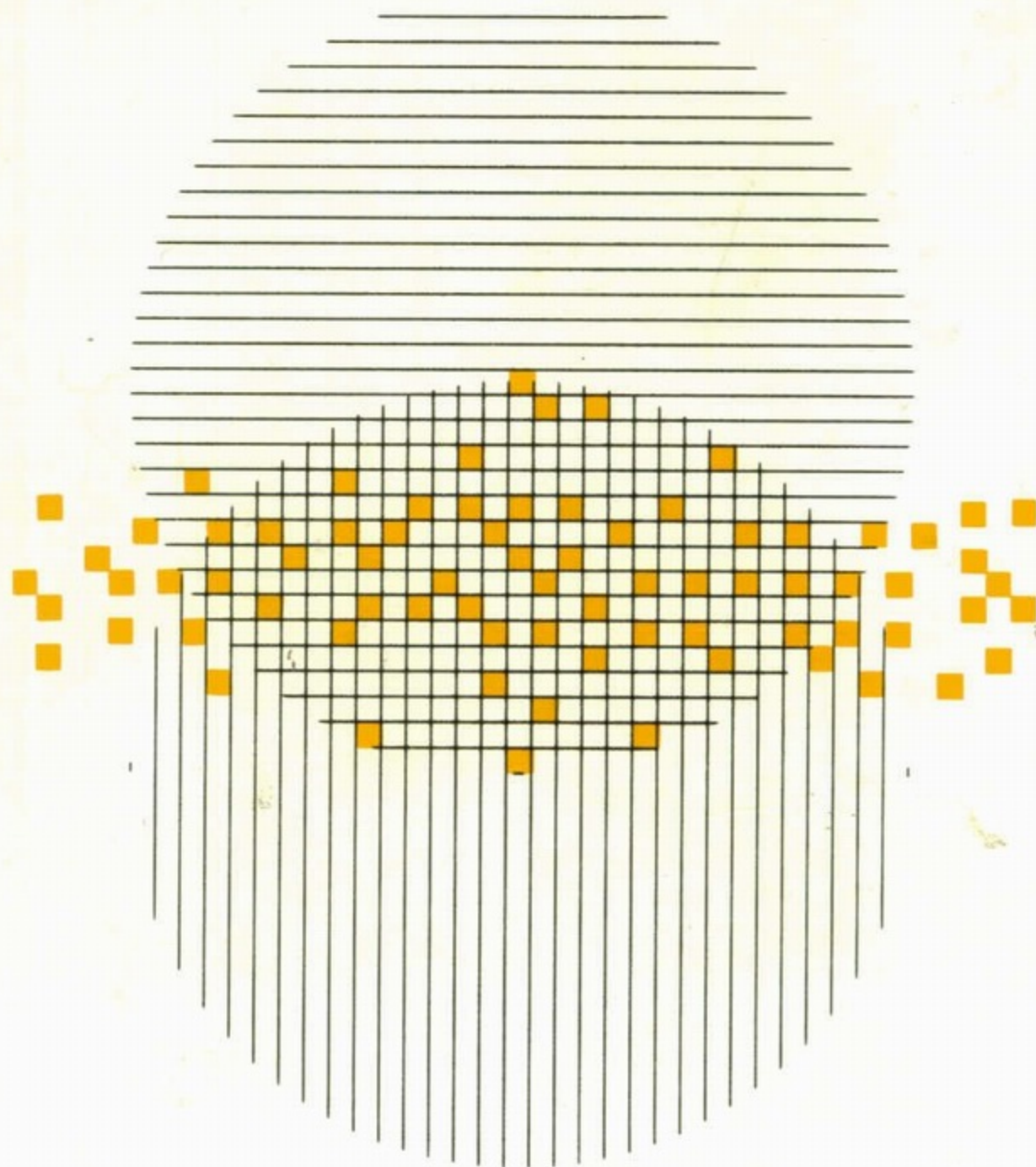


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ENGINEERING MANAGEMENT

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ENGINEERING MANAGEMENT

DAVID I. CLELAND

Professor of Systems Management Engineering
School of Engineering
University of Pittsburgh

DUNDAR F. KOCAOGLU

Associate Professor of Industrial Engineering
Coordinator, Engineering Management Program
School of Engineering
University of Pittsburgh

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ENGINEERING MANAGEMENT

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23456789 HDHD 89876543

This book was set in Helvetica by A Graphic Method Inc.

The editors were Julianne V. Brown and J. W. Maisel;

the designer was Nicholas Krenitsky;

the production supervisor was Charles Hess.

The drawings were done by A Graphic Method Inc.

Library of Congress Cataloging in Publication Data

Cleland, David I

Engineering management.

(McGraw-Hill series in industrial engineering
and management science)

Includes index.

1. Engineering—Management. I. Kocaoglu,

Dundar F., joint author. II. Title.

TA190.C58 620'.0068 80-20369

ISBN 0-07-011316-5

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WHY 1 ENGINEERING MANAGEMENT?

Nothing is more important than an idea whose time has come. Engineering management has existed for many years as a vital function in technology-based organizations. Recently it has started to gain recognition as a discipline in its own right, different from engineering specialties and also different from general management. Considerable attention is now being directed toward educating engineering managers, who play a dual role as the linkage between management and technical expertise. Such managers allocate resources, work through people, and make and implement decisions while simultaneously formulating technical strategies.

We believe that the time has come for the identification of engineering management as a distinct professional discipline. Individuals who manage engineering organizations find it necessary to understand both the technology involved and the management process through which that technology is applied. Management literature contains very little material that deals with the dual role of the engineering manager—a technologist and a manager. This is somewhat of an enigma, for engineers have made many significant contributions to general management theory and practice.

The pioneer of scientific management, Frederick W. Taylor, who introduced basic analytic methods into factory management early in this century, was an engineer. Taylor's classic statement, "knowing exactly what you want to do, and then seeing that they do it in the best and cheapest way," introduced the era of scientific management at the shop level. Henri Fayol, another engineer, is credited with being the father of modern management theory. Fayol's book, *General and Industrial Management*,¹ is truly the outstanding classic in management theory. Any individual who calls himself a manager should read this book.²

¹Henri Fayol, *General and Industrial Management*, Pitman, London, 1949.

²Harold Koontz and Cyril O'Donnell, in their *Principles of Management*, 3rd ed., McGraw-Hill, New York, 1964, make this claim. They state: "A study of Fayol's monograph, with its practical and clear approach to the job of the manager and its perception of the universality of management principles, discloses an extraordinary insight into the basic problems of modern, business management" (p. 17). Few management scholars would question their judgment of Henri Fayol.

The more recent contributions of engineers and scientists to management have been in the management science-operations-research area. Perhaps this has been so because the mathematical approach to management complements the quantitative background of the engineer.

Yet when one reviews some of the extraordinary contributions to management theory and practice that engineers have made, one is struck by an irregularity: while engineers and scientists have made many contributions to management theory, there have been only a few books written in recent years on engineering management.

It can be argued that the engineer is in somewhat of an identity crisis, not knowing whether to be a technologist for technology's sake or to serve more in a bridging role between science and social demands. Industries develop as the result of a demand when resources to satisfy it are available. The most significant danger for an industry is its preoccupation with its product rather than the business that it is in. Development of engineering in its modern shape as a discipline in the nineteenth century was a direct response to demand for an interface between two isolated segments of society: one represented by society's need for products, the other by the availability of scientific methods and discoveries. Based on this starting point, it is possible to define the *business* that engineering is in as the interaction between those two segments.

This definition necessarily imposes upon engineers the responsibility of integrating and managing all aspects of technical, social, and economic systems. It is questionable, however, as to what degree they are prepared to assume this responsibility. In the present educational system, all engineering students are required to get a broadly based, often highly theoretical background in basic scientific areas. The bright students are then encouraged to undertake a more analytical and abstract study at graduate level. Because of the limited nature of course work in creative applications of technology to realistic problem solving, the graduates usually have little idea of the real needs of the society that they are expected to serve in the capacity implicit in the fundamental purpose of engineering. According to Karger and Murdick, this is a form of myopia, probably gained from the engineering curriculum which is "jammed with mathematics, science, and engineering courses. . . . Engineering curricula seldom require the student to study economics and business management, yet such knowledge is at the heart of 'making science practical for mankind.'"³

As a possible solution for this myopia, Karger and Murdick suggest: "Require all engineers to take the equivalent of a three-credit-hour course covering all aspects of new-product problems and

³Delmar W. Karger and Robert C. Murdick, "Engineering Myopia," *IEEE Transactions on Engineering Management*, February 1977, p. 24

a three-credit-hour course covering all aspects of engineering management".⁴

Although the present engineering education is satisfactory by way of providing technical skills and knowledge, its ability to produce students who have an adequate appreciation of engineering management has to be questioned.

To paraphrase J. W. Forrester,⁵ who has spoken of the need for the engineer to integrate technology, economics, management, human behavior, and marketing in his work, engineering education gives the student only scientific tools, with just a slight touch on the other subjects in an informal fashion. The engineer has to make decisions based on inadequate information, trying to optimize resources in an uncertain environment, yet at school he primarily deals with essentially deterministic systems. As a manager of socio-technological systems, the engineer has to have conceptual skills and leadership qualities, yet very little of his formal education is directed toward developing them. In analyzing future skills and knowledge requirements for engineers, Forrester recommends that attention should be focused on educating a new breed of engineer, the enterprise engineer, whom he describes as a leader, a designer, a synthesizer and a doer, who understands theory as a guide to practice, and concerns himself with human organization because the pace and success of technology are becoming more dependent on interaction with the social system and less on scientific discovery.

Traditionally, young engineers have considered management as being too intuitive, not based on hard facts and analytical approaches. This perception has led to an almost artificial line of demarcation between the two disciplines. In reality, engineering and management are logical complements of each other. No major technological problem can be solved in a vacuum without explicit recognition of the nontechnical factors such as the social, legal, and economic conditions. Conversely, in a complex society, no major problem can be solved outside the technological system. The engineer, therefore, frequently has to make decisions which go far beyond the boundaries of his technical specialty.

Because of the unique problems and cultural implications of engineering environment, the management of technologies requires a solid engineering background. It would be a naive expectation to assume that nonengineers could become successful engineering managers. On the other hand, it is also naive to assume that successful engineers necessarily become successful engineering managers. No data are available to support either of these assumptions.

An intuitively realistic hypothesis about the engineering-

⁴Ibid., p. 25.

⁵J. W. Forrester, *Engineering Education and Engineering Practice in the Year 2000*, paper presented at National Academy of Engineering, University of Michigan, Ann Arbor, Sept. 21, 1967.

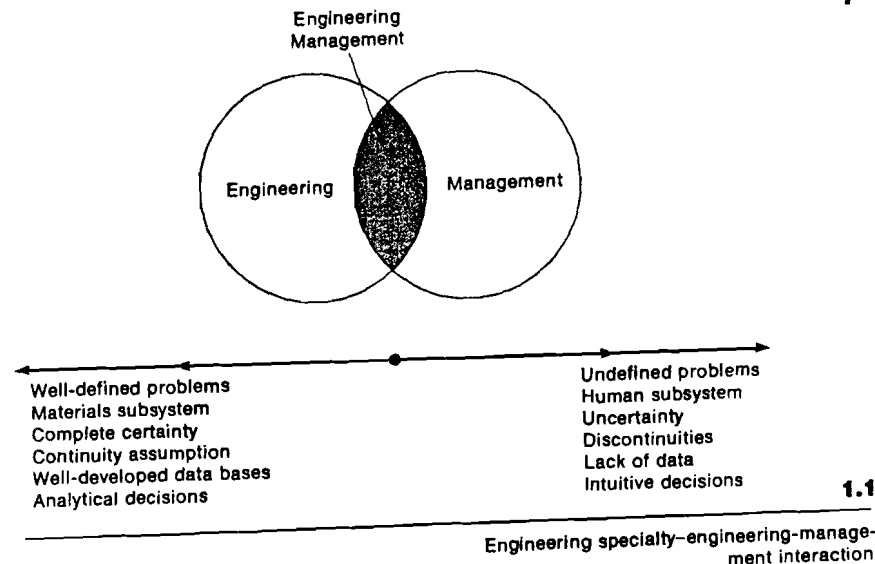
- 6 management interaction could be made as follows: "Successful performance in an engineering specialty is a necessary but insufficient condition for successful engineering management."

This book is addressed to engineers moving into engineering-management positions. Management science techniques and management-theory concepts are blended to give the engineer a balanced exposure to the qualitative and quantitative aspects of management. A rational basis for decision making is developed throughout the book. The emphasis is on the formulation of engineering management problems and the interpretation of their results. The organizational problems of planning, controlling, and scheduling are evaluated in terms of engineering resources and interactions among those resources. The objective of the book is to channel the rational decision-making capability of engineers toward the analysis of engineering management problems. The project orientation of the engineering environment is used as the focal point of the book. The concepts and methods are developed around it.

ENGINEERING TO ENGINEERING MANAGEMENT

Engineering and management have the same basic philosophies, even though the specific nature of the problems are different in the two disciplines. Both engineers and managers are trained to be decision makers in a complex environment. They both allocate resources for the operation of existing systems or for the development of new systems. Both have to recognize, identify, and evaluate the interfaces among system components. Engineering and management decisions differ only because of their emphasis on different subsystems. The engineer is primarily interested in the materials subsystem, dealing with the methods and processes for the allocation of material-related resources to the design, development, and operation of engineering systems. He goes through a rational thought process in his decisions, justifying each step with facts, measurements, and functional relationships that can be proved. His statements are precise and measurable; his thought process is traceable and his decision steps are reproducible for another engineer to accept or refuse the recommendations. He frequently works with relatively well-defined problems in an environment where uncertainties are reduced significantly by the information available about the behavior and properties of materials with which he deals.

A manager's primary emphasis, on the other hand, is on the allocation of human and nonhuman resources to perform the tasks demanded of his organization. His problems are usually more open-ended and less well defined than the engineer's problems. He works in a considerably more uncertain environment compared to an engineer because of the unknowns involved in human behavior and the



external conditions that affect his decisions. He operates in a rapidly changing, discontinuous environment where precise functional relationships are difficult to develop, yet he has to make rational decisions and justify the steps of his thought process. Figure 1.1 depicts the interaction between engineering and management and the overlap between the two fields.

ASSUMING MANAGEMENT RESPONSIBILITIES

The engineer, with his analytical background and training in rational decision making, is a logical candidate for management responsibilities. In fact, according to a recent survey conducted in several technology-based corporations in Pittsburgh over 45 percent of engineers in the 25 to 45 age interval were found to have some form of engineering management responsibility, ranging from staff positions with indirect supervision to the position as head of engineering.⁶ According to the Engineering Manpower Commission, the corresponding figure for all engineers in the United States is as high as 82 percent.⁷ Other surveys indicate that 40 percent of industrial executives and 34 percent of all top corporate managers in the United States have engineering backgrounds.⁸ Change affecting the career

⁶This survey was conducted by the engineering management program at the University of Pittsburgh.
⁷*The Engineer as a Manager*, Engineering Manpower Bulletin 25, September 1973.
⁸Personal correspondence with Dr. R. A. Brown, Industrial Engineering Department, University of Alabama in Huntsville.

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of an engineer includes those changes which threaten to make his engineering credentials obsolete as well as those that redirect his career. A report of the Carnegie Foundation noted: "The most important fact brought out by . . . surveys over a period of thirty years is that more than 60 percent of those persons who earned [engineering] degrees in the United States, either became managers of some kind within ten to fifteen years or left the engineering profession entirely to enter various kinds of business ventures."⁹

Management opportunities become available to engineers at a relatively early point in their careers. During the 25- to 30-year age period the young engineer has duties that are largely technical in nature. As the age level increases, administrative duties expand rapidly. The percentage of engineers in team supervision is highest in the 31- to 35-year age group. The proportion of project managers peaks at 36 to 40 years, while that of division managers is highest from 46 to 60. By the time engineers are 41, two-thirds or more will have taken on management duties of an increasingly responsible nature. Figure 1.2 summarizes these statistics based on a survey conducted by the Engineers Joint Council.¹⁰

Engineers reach a decision usually between 3 and 7 years after graduating with an engineering degree. They find themselves in need of choosing between a technical specialty, a technical management position, or a nontechnical management job. There are two reasons for this situation:

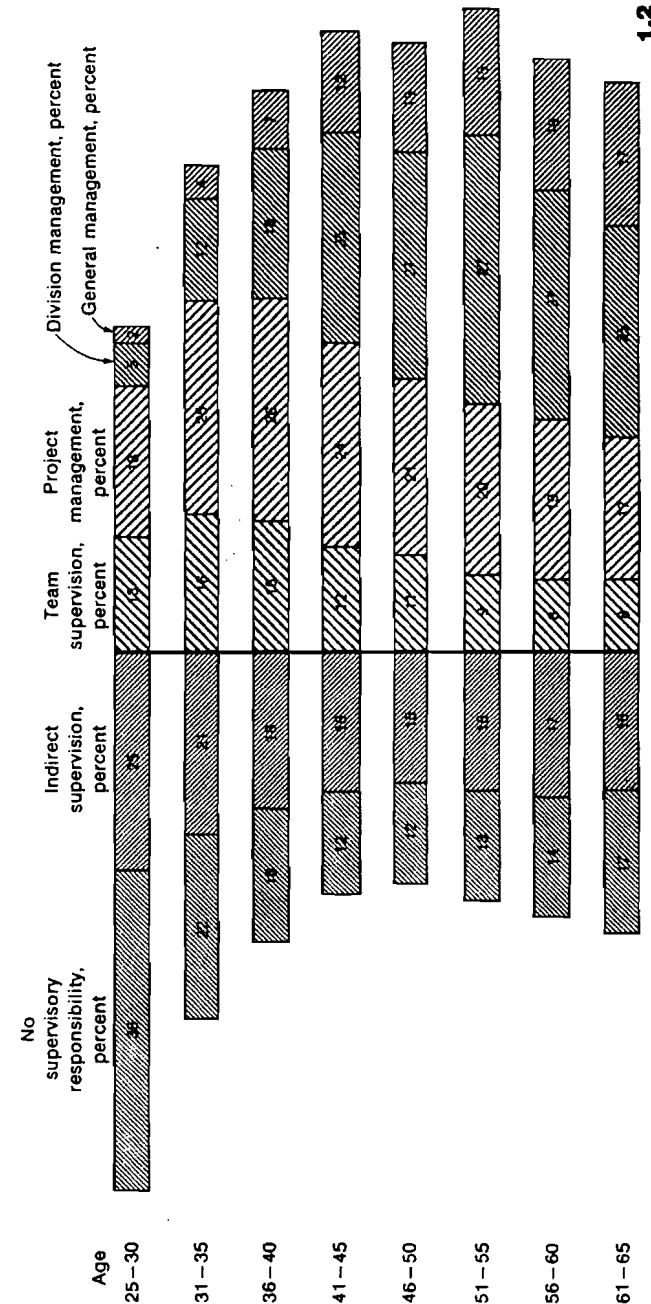
1 Engineers, by the nature of their profession, are thrust into a management ambience by assignment to an engineering project almost immediately upon graduation. In an engineering project, they have to deal not only with the materials subsystem but also with the relations among the members of their project team as well as the other specialists from functional groups. They must consider the financial impact of their technical decisions. In a short time they discover that they must work through others, such as draftsmen, designers, and other engineers either directly or indirectly.

2 The reward system in industry, by and large, seems to favor individuals moving through the management, rather than the technical specialty ladder. The dual-ladder concept has been tried in several large companies, but the successful implementation of that concept has been very limited.

⁹Russell L. Ackoff, *Redesigning the Future: A Systems Approach to Societal Problems*, Wiley, New York, 1974, p. 80

¹⁰*The Engineer as a Manager*, Engineering Manpower Bulletin 25, September 1973.

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Engineering management responsibility as a function of age. (From *The Engineer as a Manager*, Engineering Manpower Bulletin 25, September 1973.) Percentages do not add to 100 in some cases because numbers have been rounded off.

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Even though the engineers are required to make this important choice at an early point in their career path, they realize that they have not been prepared to make management decisions while simultaneously formulating technical strategies. The two roles that they have to play represent different underlying cultures even though both are based on the premise of rational decision making. The engineering education has been very successful in preparing engineers for solving technical problems, but it is not directed toward the management aspects of the engineering profession.

MANAGEMENT KNOWLEDGE REQUIREMENTS

The next excursion for the engineering manager out of his technical discipline is into the world of broad social, economic, regulatory, and environmental considerations. These considerations are not new, but they are certainly accelerating in their impact on engineering decisions. One only has to read of the products that are being recalled by manufacturers for repair or the number of class-action suits in our courts to see the growing impact of social and regulatory considerations. To illustrate the regulatory dimension, an article in a recent trade journal pointed out that over 200 new federal regulatory agencies or departments have been created in the last 10 years. But there is a bright spot in all this—twenty-one such regulatory agencies have been eliminated!

We are not taking issue with this regulatory aspect of the industrial world. Our point in bringing this up is merely to state the emphasis being placed on regulation by our government and the impact this has in influencing the decision aspects for the engineering manager.

One cannot reasonably expect the engineering manager to be expert in all these matters of regulatory, social, and environmental considerations. But he should know enough to know when he needs help. Then he can seek the professional assistance needed to advise him on the impact an engineering management decision can have on the total picture, for the present and for the future.

An example of the complexities of decisions in a major technological project is the multitude of issues surrounding the supersonic transport (SST). When the United States decided to abolish the development efforts in the early 1970s, it was not because of a lack of technical expertise in the field. Rather, the decision was based on the seemingly nontechnical considerations dealing with the economics of the SST, the environmental factors, the legal aspects, the political implications, and so forth. Even if it was a technological triumph, the American SST did not become a final product because of these peripheral issues. The engineering decisions dealing with the materials subsystem and the technological requirements were not adequate to bring the project to a successful completion.

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THE ENGINEERING MANAGER'S JOB

The nature of an engineering manager's job and the responsibilities involved center around the process of *making and executing* engineering and engineering management decisions. Routine decisions are never easy, but they are far easier than those complex strategic decisions whose impact on the engineering project may be felt several years into the future. These decisions, growing out of the planning process, are facilitated by the use of modern quantitative management techniques. Such techniques have come into favor as ways to better evaluate the risk and uncertainty of engineering management decisions. The engineering manager requires enough sophistication in these techniques to realize that quantitative approaches to management can be a valuable aid to complement his judgment.

We must accept also that an engineering manager's role requires an adequate working knowledge to permit him to manage a team of professionals and at the same time serve in a fiduciary function for his portion of the company's capital investment and expenditures.

All this leads us to the conclusion that engineering managers wear two hats: the technical hat and the management hat. It should be abundantly clear that education and training beyond the technical training usually received is required. This, coupled with the engineering manager's need to remain abreast of the state of the art, is an obvious challenge.

EDUCATIONAL NEEDS

To what extent does traditional engineering education prepare the engineer for assuming managerial responsibilities? Very little, we believe. The classical engineering subjects do little to develop managerial knowledge and skills. The needs an engineering manager would have to satisfy in order to be a successful manager include the following:

First, and of primary importance to every step of the engineering process, are the economic considerations that enter into the decisions involving the application of technologies. A knowledge of engineering economy is an essential ingredient for engineers and those who aspire to effectively manage engineers.

Next is the evaluation and selection of alternatives in engineering design and resource allocation decisions. When an engineering manager has to determine which engineering project to select and how to distribute his human and nonhuman resources to the various activities in the project, he needs analytical techniques to make the best decisions. The conditions under which the decisions are made are not purely rational, since the engineering manager cannot always afford the luxury of evaluating all alternatives to reach the so-called best or optimum decision. However, the opposite of rational

decision making is intuition and the seat-of-the-pants type of management. Intuitive decisions have a justifiable basis if cast in the context of the manager's personal belief, experience, and feel of the situation. Such decisions cannot be subjected to an analytical evaluation, nor can they be traced back systematically. Therefore, even when the engineering manager operates under the "bounded rationality principle" of Herbert Simon,¹¹ he needs the concepts, tools, and methods of rational decision making. These tools are available in the body of knowledge known as management science.

Another consideration in educating the engineering manager is to develop the necessary skills and attitudes to work harmoniously and cooperatively with people in the organization—subordinates, superiors, peers, and associates. There are no peopleless organizations! An engineering manager must develop the knowledge, skills, and attitudes conducive to being recognized as a leader in his organization. This is a departure for the engineering manager from the relatively predictable world of engineering to the unpredictable world of human behavior. People working together to accomplish a goal require a form of organization—either formal or informal. Today's engineering departments tend to be formal organizations; the person who manages such an organization should have a basic working knowledge of organization theory as it relates to his environment. The engineering manager need not become an expert in organization theory, but he should understand the basic principles of organization and some of the alternative ways of organizing engineering resources, such as the use of the matrix-organization approach.

The need for the engineer to know something of organization theory, particularly the idea of the matrix organization, can be illustrated by describing the new organizational concept in engineering management instituted by General Motors, viz., the *project center*.¹² This concept in management was devised to coordinate the efforts of development engineering in the five automobile divisions in General Motors. A project center consists of engineers temporarily assigned from the divisions to work on a new engineering design. If a major new effort is planned—a body changeover, for example—a project center is formed across the automobile divisions to operate for the duration of the change.

Project centers work on engineering equipment common to all divisions, such as frames, steering gear, electrical systems, and so forth. The project center complements but does not replace the lead-division concept, where one division has primary responsibility for

taking an innovation into production. The interpersonal relations this new project-center concept facilitates are noted by one General Motors executive in this fashion:

"We become masters of diplomacy," says Edward Mertz, assistant chief engineer at Pontiac, who was manager of the now-disbanded A-body project center. "It's impossible to work closely on a design without influencing it somewhat. But the [project] center can't force a common part on a division." Indeed, many of G. M.'s engineers feel the project-center innovation has actually helped enhance the divisions' individuality, by freeing some of them to work on divisional projects.¹³

In actuality, General Motors has adopted what has become known as the "project management" approach to organizing and managing engineering projects.¹⁴ From an organizational viewpoint this technique is usually called the "matrix organization"; it results when teams of people drawn from different disciplines are formed to work on an engineering problem. This approach can help engineering managers delegate authority, thus freeing them from involvement in detailed decision making.

It seems quite appropriate to assume that a majority of engineers in the future will continue to integrate technical management responsibilities at some stage in their career, and the proportion of their time spent on such duties will increase as they grow older. Engineers, seeing the need to acquire management knowledge and skills, have created a demand for engineering management programs in universities. Such curricula are usually offered in engineering schools for engineers moving into management positions while maintaining their identity within their technical specialties. One can assume that these programs will continue to provide the future engineer-manager with the required educational opportunities. A brief review of a typical engineering management program gives an insight into the educational experience these engineering managers-to-be hope to acquire.

TYPICAL ENGINEER MANAGEMENT PROGRAM

The typical engineering management program is designed to develop within the student a broad knowledge of the management of technical and scientific organizations. The plan of instruction in such programs has been designed to provide the candidate with the qualitative and quantitative skills necessary to hold management positions in

¹¹This principle is discussed in detail in D. W. Miller and M. K. Starr, *Executive Decisions and Operations Research*, Prentice-Hall, Englewood Cliffs, N.J., 1960.

¹²See Charles G. Burck, "How G. M. Turned Itself Around," *Fortune*, Jan. 16, 1978, pp. 87-100.

¹³Ibid., p. 96.

¹⁴Project management is more fully discussed in Chap. 2. The reader who wishes to study even more of the details of project management is invited to peruse D. I. Cleland and W. R. King, *Systems Analysis and Project Management*, 2d ed., McGraw-Hill, New York, 1975.

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engineering and scientific organizations. These quantitative and qualitative aspects of managing technical and scientific organizations are typically integrated within a *systems approach*. The program of instruction offers both theoretical and applied subjects with sufficient flexibility to appeal to the student who has had experience in working in the real world.

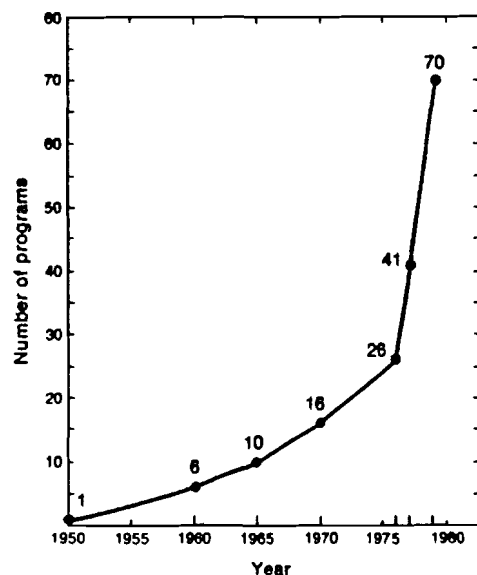
Based on the experience at the University of Pittsburgh, a profile can be developed of the typical engineering management student. Such a student is about 30 years old, with a B.S. in engineering and an average experience of approximately 8 years. He works in an organization that is based on science and technology, either as a technical specialist or at the entry level of technical management. If he holds a nonsupervisory position, his objective is to prepare himself for management responsibilities through the engineering management program. If he is already a technical manager, he wants to broaden his skills for his present position.

In general, he looks for well-planned, structured guidance in the courses he takes. He sees the value of blending the management concepts and management science methodologies in his education and emphasizes the need for relevance in the courses. The engineering management student typically describes himself as a results-oriented, analytical person. He is a successful engineer and sees himself getting immersed increasingly in his field of specialization while management opportunities start developing around him. He feels that he has already proved himself as a successful technologist and there is not too much more to look forward to if he continues as an engineering specialist. He feels he can have upward mobility through the engineering management route, but he knows that he is not qualified to tackle the management problems because he does not have the skills, knowledge, and attitudes necessary for engineering management responsibilities. He has chosen the engineering management program to prepare himself for the challenges of the role that the engineering manager plays by combining management and technical expertise. He feels that such a program is directly addressed to the needs of a technical-scientific manager.

THE GROWTH OF ENGINEERING MANAGEMENT PROGRAMS

Engineering management programs have grown in popularity significantly in the last several years. In 1980 there were more than seventy engineering management programs at graduate level around the country, and the number was still growing rapidly, as shown in Fig. 1.3. Professional societies have also recognized this trend in engineering management programs and have responded accordingly. The American Society for Engineering Education (ASEE) now has an engineering management division addressed specifically to the educational aspects of engineering management. The Institute of Manage-

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1.3

Growth of graduate-level engineering management programs. (From Dundar F. Kocaoglu, "Master's Degree Programs in Engineering Management," *Engineering Education*, ASEE, January 1980.)

ment Sciences (TIMS) has a division called the College on Engineering Management, dealing with decision-making methodologies for both technical and management decisions. The American Society of Engineering Management (ASEM) is a professional society that brings together the practitioners and academicians to share their views on engineering management.

If the increasing popularity of engineering management programs in the United States colleges and universities is any indication, then engineering management is indeed a profession whose time has come.

ENGINEERING MANAGEMENT PROCESS

An engineering manager who aspires to improve his management performance must develop knowledge, skills, and attitudes in the context of a management philosophy. Such a philosophy must be built on a framework of management theory. We suggest as a starting point the acquisition of knowledge of the major activities that an engineering manager engages in as he manages an engineering organization.

These management activities, or as they are more commonly called, functions, were first put forth in their modern sense by Henri Fayol. Fayol described these activities in terms of planning, organization, command, coordination, and control. His definition of managerial activities is itself a primer in management theory. According to Fayol:

To manage is to forecast and plan, to organize, to command, to coordinate and to control. To foresee and provide means examining the future and drawing up the plan of action. To organize means building up the dual structure, material and human, of the undertaking. To command means maintaining activity among the personnel. To coordinate means binding together, unifying and harmonizing all activity and effort. To control means seeing that everything occurs in conformity with established rule and expressed command.¹⁵

If we briefly examine management functions in the circumstances of an engineering environment, we can appreciate the particular challenges facing the engineering manager. We have changed these management functions somewhat from the concepts put forth by Fayol.

PLANNING

Planning is the process of examining the potential of future environments, establishing goals and objectives which accommodate the future, and designing a strategy outlining how goals and objectives will be attained. Planning has a time dimension: short-term, usually the forthcoming year; and long-term, those periods beyond a 1-year time. An engineering manager has to be concerned with both long and short terms when planning for his technical discipline. Planning in the short term is necessary to provide engineering design support to emerging projects and to ongoing products that are being manufactured. In addition to this, an engineering base technology has to be maintained and a discipline provided in the state of the art. The pace of technology in modern industrial organizations requires that engineering contribute to the strategic direction of the organization. Thus engineering managers need to be concerned with developing long-range or strategic plans for their discipline.

Adequate planning of engineering effort is one of the most difficult of the functions that face the engineering manager. Perhaps this is why this function is often neglected.

If the chief executives have not endorsed an active strategic planning program within the corporation, the engineering manager's job becomes more difficult. Even with financial and moral support

¹⁵Fayol, op. cit., pp. 5-6.

from key corporate executives, long-term engineering problems can seem almost insoluble. New technologies and complex, unique devices that can threaten the technical competitiveness of a product are appearing almost routinely.

Even the planning for support of ongoing products is complex in today's industrial enterprise. The simple task of predicting engineering design hours is a case in point. Past experience is hardly adequate. Estimating personnel, schedule, and product performance is becoming more difficult for the engineering manager. Today, it is common to find professional planners on the staff of section-level engineering managers.

Planning involves answering the question "What are we aiming for and why?" It is an activity where problems will become the rule for those who must make decisions on how engineering resources will be used in the future.

Technical goals and objectives are established by a careful examination of the technological capabilities of the engineering organization. They specify the direction in which the organization will move. The value structures of the managers, the needs for engineering services and the opportunities, and the outside environment play important roles in the development of objectives. Once the objectives are determined, the strategies are developed to achieve them within the limitations imposed upon the engineering organization by the external conditions. Thus, the strategies have to be formulated according to the best estimates available for the future. These estimates can be obtained through technological forecasting. The purpose of technological forecasting is to determine where it is possible to go from here and what the dangers and opportunities are. As a result of technological forecasting, the organization may revise its objectives and develop a more refined concept of where it intends to go.

Several methods can be used for the purpose of technological forecasting. Time-series analysis is one of the methods. It involves statistical analysis of trends in technologies observed in the past. Other methods take future discontinuities into account by using expert opinion in determining possible breakthroughs, potential directional changes in needs and requirements, and technological capabilities required for the developing needs. Such methods as morphological analysis, cross-impact analysis, and Delphi method are useful for probing into the future to identify new technology prospects and to estimate their timing. Another approach that has proved to be successful in technological forecasting is the development of scenarios¹⁶ in systematic brainstorming sessions. The scenarios describe possible future environments by ask-

¹⁶The concept of scenarios has been developed by Herman Kahn in *The Year 2000*, Macmillan, New York, 1967.

18 ing "what if" questions about the various political sequences of events.

When developed properly, technological forecasts present a blueprint of the future with respect to technical requirements and their proper timing.

Once the ideas about the future are developed and the technical objectives are refined, the engineering manager formulates strategies to accomplish those objectives in the possible futures that have been predicted. Each strategy represents a different resource profile. Depending upon the resource availability and the estimated outcome of each strategy, he then selects the best alternative to move his organization from where it is to where it should be. Management science techniques described in Chaps. 7 through 11 can be used in selecting the best alternative and allocating the available resources in the best fashion.

ORGANIZING

The management function of organizing is concerned with the question "What's involved and why?" This function deals with how people and nonhuman resources are acquired and utilized in the engineering activity. The common denominator of the human element in an engineering organization is the pattern of authority and responsibility that exists—both formal and informal. In the formal sense, authority and responsibility are dependent on how the people are aligned in some organizational structure. The organization chart usually used to portray this alignment is often referred to as a *model* of the organization. The engineer-reader probably thinks of the term "model" in a different sense—perhaps in a mathematical sense. A model, however, is some degree of representation of the real world. An organization chart is a representation of the real world of how human and nonhuman resources are aligned to do something.

Engineers and those who manage engineers often view the subject of organization with distaste. This is exemplified by the comments one often hears along the lines: "We have a dynamic organization—every few weeks we 'reorganize' things!" There is much truth in such a statement; in an engineering department people are shifted around to support workforce requirements of the engineering projects. Skill-level requirements change during the life cycle of these projects; the ability to change the assignment of people from one project to another with minimum disruption of efficiency is always needed. Little wonder that engineers view organization with misgiving.

An organization should be viewed as a dynamic, goal-seeking, purposeful system. Organizations are not static—i.e., without motion. They change as the demand for the organization's services changes. The changing nature of modern engineering organizations

conflicts with the needs of people who seek security and stability in their work environment; extreme care is required to avoid conflict between engineering managers and the people who provide engineering support. Successful leadership—personal leadership—is required of those managers who aspire to effective management of engineering activities.

MOTIVATING

A leader is someone who leads people. While this statement is obvious and oversimplified, it is basically true. People are led by ideas and actions; usually there is some system of rewards and punishments that serves to motivate people—or demotivate them. Engineers and scientists are by education and training inclined to act rationally and objectively about their engineering work. In their interpersonal relations and in their motivational factors, however, they are probably no more rational and objective than anyone else.

Motivating is that portion of a manager's job that deals directly with the human element—the face-to-face personal leadership role the manager must exercise. People are motivated by a wide variety of factors and forces. "Coercion," "conniving," "compensation," and "human relations" are some of the terms that come to mind when the subject of motivation comes up. Motivation will be dealt with in much greater detail later in the book. For the present, we need to stress the fact that motivation is one of the key management functions about which the engineering manager must be concerned. The reader should be able to recollect situations in his career where an engineering manager's personal style of leadership was instrumental in bringing out the best in people. Conversely, the reader can probably also recall managers whose style of leadership was detrimental to motivating people.

The matter of professional obsolescence poses a particular challenge to the engineering manager. Not only do many engineers gravitate to management positions as they grow older, but they are subject to obsolescence on the job. The job performance of engineers tends to peak in their middle to late thirties. According to Dalton and Thompson, "the years of high performance are starting and ending sooner."¹⁷ The aging of technically educated and trained people in the workforce today is unique. Paraphrasing Dalton and Thompson, "no generation of managers has had to deal with this phenomenon before."¹⁸

Motivation deals with the question, "What encourages people to do their best work?" The challenge to the engineering man-

¹⁷Reprinted by permission of the *Harvard Business Review*. Quoted from "Accelerating Obsolescence of Older Engineers," by Gene W. Dalton and Paul H. Thompson (September-October 1971), p. 57. Copyright © 1971 by the President and fellows of Harvard College; all rights reserved.

¹⁸*Ibid.*, p. 58.

agers is clear. They will have to find ways to motivate technical people.

DIRECTING

Directing is the management function that is concerned with giving guidance or instruction to those people with whom one shares the running of the organization. Directing is like the management function of motivating that was discussed in the previous section. Motivating might be thought of as a *humanistic* approach to giving direction. Both directing and motivating have strong face-to-face leadership overtones. Both are involved in the day-to-day activities associated with influencing, guiding, and supervising in accomplishing the engineering objectives established through planning. Carrying out the directing function can be as straightforward as the giving of a specific order to an individual. Giving an unobtrusive suggestion to a person who is being counseled is another aspect of directing. As a distinct function of an engineering manager, directing is concerned with the making and execution of decisions—the matter of “Who decides what and when.”

The directing function is carried out by an engineering manager who is authorized by organizational policies to make a decision, e.g., approve an engineering change for a development project. A project manager may not have the authority to approve an engineering change without coordinating the change with several other people in charge of such functions as contracting and cost estimating, as well as with the engineering manager. In this situation the project manager, although lacking the formal authority to make the engineering decision, would be responsible for seeing that the decision was made by the person so empowered.

The directing function provides guidance to the people with whom one works, either as a decision maker *per se*, or through an administrative mechanism to bring about a decision. Indecisiveness—the inability to make a decision—is a difficult situation in any organization. Some managers are indecisive; the people with whom such managers work can become frustrated waiting for a decision. A famous World War II Air Force general is reputed to have had a motto posted in his office which proclaimed: “A bad decision is better than no decision at all!”

The directing function highlights the need for the engineering manager to realize that he is the one who must assume responsibility to see that engineering decisions are made in a timely and relevant fashion.

CONTROLLING

Controlling is the key management function that sees “that everything occurs in conformity with established rule and expressed com-

mand.” This definition of control is credited to Henri Fayol. We do not believe that anyone has said it any better. Controlling the activities of an engineering organization requires that objectives, goals, policies, procedures, feedback, information, and performance standards be in existence. The engineer will readily relate to the notion of control in a mechanical feedback control system. Control of engineering activities is not as precise; the fundamental similarity is the same, however.

Control is too often associated with the idea of the negative constraint of people—a restriction of the personal liberties of people in their workplace. This association is most unfortunate. Control addresses the question “Who judges results and by what standards?” We believe that professional people are anxious to do good work; they need to know how they are doing. Control looks to the development of performance standards for people and organizations and provides feedback so that progress toward objectives and goals can be effectively sustained.

An engineering project manager constantly evaluates the performance of his team members and measures the achievement level of the project for which he is responsible. These measurements have to be compared with standards to determine the need for corrective action in order to reach the cost, time, and technical performance objectives of the project. The standards are established in the initial stage of the project in form of budgets, technical targets, and time schedules. The budget is the cost profile for the engineering services. It is based on the best estimates of the costs available. Technical targets are the specific results expected to come out of the engineering efforts. In an engineering project for the design of an industrial plant, the technical targets could be the feasibility studies, the plant requirements, and the design of the structural, mechanical, and electric parts. These are broadly defined in the beginning of the project and refined as the project proceeds.

The time schedule shows the relationship among various engineering activities and the time estimates for each one. The tasks to be completed before another one can start are identified and listed in a systematic way. Graphical methods can be used for this purpose. The simplest method is the Gantt chart, shown in the simplified example in Fig. 1.4. A more sophisticated approach is the use of network techniques discussed in Chap. 11. The procedure for these techniques involves the identification of individual tasks, the precedence relationships among them, and the time estimates and the development of a network such as the one shown in Fig. 1.5. Since the duration of each task (structural design, etc.) is already estimated, the engineering project manager responsible for the project compares the actual time spent on each task with the estimated time. If the project is falling behind schedule, he either shifts his resources toward the more time-consuming tasks or revises the initial estimates.

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Activity	Time schedule				
	January	February	March	April	May.....
Feasibility studies					
Plant requirements					
Structural design					
Mechanical design					
Electrical design					

1.4

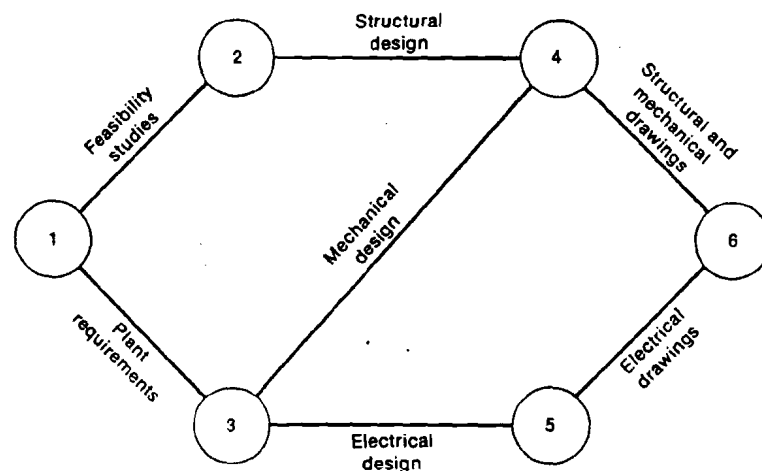
Gantt chart.

The engineering project manager's responsibilities in controlling the team can be defined as:

- 1 Setting the time, cost, performance standards
- 2 Measuring the time, cost, and performance characteristics in the project
- 3 Comparing the measured results with the standards set in step 1

A simple project network.

1.5



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- 4 Taking corrective action to bring the actual performance close to the projected performance

This is a continuous process. After step 4, the project manager goes back to step 1 and follows the same steps.

The management functions (planning, organizing, motivating, directing, and controlling) are interrelated and inseparable. For example, to plan one must:

Organize the people and other resources that will be used during the planning process.

Motivate the people to take time from their current work to plan the utilization of resources in the future.

Facilitate the making of planning decisions and provide leadership for those people who do the planning.

Develop performance standards in the planning process which can be used to compare actual and planned results during the control process.

When one carries out the organizing function one must:

Develop an organization plan for how authority, responsibility, and accountability are to be allocated among the people in the organization.

Establish resources, such as salary-incentive programs, off-duty educational programs, opportunities for attending at professional meetings, and so forth, to help motivate professionals in the organization.

Set up a decision process to determine who has what authority to make which decisions. This includes providing the leadership to see that decisions are made on a timely basis.

Institute an information system for providing intelligence on where engineering projects stand in relation to their objectives, budgets, and schedules. Such information provides the basis for controlling the future application of resources to these projects.

So it goes on, with each engineering management function related in some manner to each other.

What does an engineering manager really do? The engineering management job consists of a few things that can be simple in statement but complex in execution: (1) Create an intellectual and physical environment whereby the members of the engineering community can work together with economic, social, and psychological satisfaction; (2) work with the members in establishing and ac-

- 24** accomplishing organizational and personal objectives, goals, and strategies; (3) periodically review and appraise personal and organizational performance; (4) create a workable set of policies and procedures that will help the members of the organization work effectively toward objectives and goals; (5) keep senior executives informed of how things are going in the technical community; and (6) formulate technical strategies.

To accomplish all this, the engineering manager can draw for assistance from a profusion of management knowledge that has been developed in other organizational contexts. This book will do this for the engineering manager through providing a primer on the application of management thought and practice to the management of resources in the technical community.

SUMMARY

The pacing factor in the application of technology is management. Professional engineers who have a solid foundation in the application of basic engineering sciences require a sound foundation in management knowledge, skills, and attitudes to take on the responsibility of managing engineering organizations.

The engineering manager's role is the link between management and technical expertise. The matching of technical resources with the needs of engineering technical professionals is a major challenge to engineering managers. The underlying concepts of engineering and management require change in the way the engineering manager views the technical environment. Passing from the role of engineer to engineering manager requires the individual to develop new knowledge, skills, and attitudes. Practicing engineering managers will find it useful to develop for themselves a personal philosophy of management that inherently contains an approach to carrying out the management functions of planning, organizing, motivating, directing, and controlling.

DISCUSSION QUESTIONS

- 1 Why is successful performance in an engineering specialty a necessary condition for successful engineering management? Why is it not a sufficient condition?
- 2 Engineers have traditionally been associated with technical decisions. Develop the evolution of engineers' involvement with management roles.

- 3 Identify some of the areas that belong to the "intersection" or overlap of engineering and management.

- 4 As implied in Question 1, what additional skills must an engineer develop in order to effectively perform managerial functions?

- 5 Try to relate the five functions of the management process to a real life situation, in the technical or nontechnical world.

- 6 Examine the six responsibilities of an engineering manager identified in this chapter. Comment and elaborate on each to make sure you fully grasp its implications.

- 7 What attitudinal changes does an engineering manager have to go through to accept his responsibilities as a technical strategist?

- 8 How has the role of the engineer in contemporary organizations changed in recent years?

- 9 What is the difference between engineering knowledge and engineering management knowledge?

- 10 How can knowledge of the matrix organizational form help the practicing engineering manager?

- 11 Is the project-center concept being used by General Motors likely to spread to other organizations?

- 12 What are some of the factors that cause obsolescence in engineers? In engineering managers?

KEY QUESTIONS FOR THE ENGINEERING MANAGER

- 1 What management philosophies have been developed in my organization for managing technical activities?
- 2 What other disciplines besides engineering do I integrate in my role as an engineering manager?
- 3 Does the role of engineering manager in my organization require a solid engineering background? Do the persons who occupy such positions have such backgrounds?
- 4 What key decisions do I make as an engineering manager? As an engineer?
- 5 Does the uncertainty of my engineering manager's role make me uncomfortable? Can I live with such uncertainty?
- 6 Have I identified the engineers in this organization who have the potential to become engineering managers? Have I helped these individuals to start a self-improvement program to develop this management potential?
- 7 What assistance have I given to the engineers in this organization to develop an awareness of the broad social, economic, and regulatory world in which they practice engineering?

- 26
- 8 What do I see as some of my personal needs for engineering management education? What is my strategy for satisfying these needs?
 - 9 Can the concept of the project center as used by General Motors be used in my engineering organization?
 - 10 What is my proficiency level in the matter of engineering management knowledge, skills, and attitudes?
 - 11 Am I perceived by my people as a leader?
 - 12 What strategies have I designed to reduce engineer obsolescence in this organization?

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PROJECT 2 MANAGEMENT

This chapter will explore the organizational concepts of project management and their relationship to the engineering community and the larger organizational context in which projects are managed.¹ Project management is so interwoven into the engineering management process that a separate chapter on this topic is required to highlight its importance to engineering management. Much of the material that is presented elsewhere in this book fits in some way into the conceptual framework of project management. Therefore, it is presented as a management technique complementary to the engineering management process.

In the last 20 years, specialized management techniques have become more sophisticated in order to manage ad hoc activities in organizations. These ad hoc activities, typically defined as *projects*, consist of a combination of human and nonhuman resources pulled together to achieve a specified purpose in the organization. Today *project management* is practiced in a wide variety of industrial environments; it is also used in educational, military, ecclesiastical, and governmental organizations. While the practice of project management doubtlessly originated in antiquity, the development of a conceptual framework of project management received much of its momentum from the work of the aerospace and construction industries. In its earliest application, project management took the form of an organizational arrangement consisting of integral teams of people working on a common organizational purpose. Such teams provided a focal point to pull together the organizational resources to be applied to a particular project. In 1964, John Mee described this arrangement as a "matrix" type of organization which entailed an organizational system designed as a "web of relationships rather than a line and staff relationship of work performance."²

To complement the organizational aspects of project management, specialized techniques and methodologies have emerged to facilitate the scheduling and budgetary activities of a project. Program evaluation review technique (PERT), progress performance

¹Portions of this chapter have been adapted from D. I. Cleland and W. R. King, *Systems Analysis and Project Management*, 2d ed., McGraw-Hill, New York, 1976, and "Defining a Project Management System," *Project Management Quarterly*, December 1977.

²John F. Mee, "Matrix Organization," *Business Horizons*, Summer 1964.

reporting, project planning with precedence lead-lag factors, network analysis, and milestone charting are a few of the techniques and methodologies that have been developed to facilitate the planning and control of projects; many of these techniques have been described in terms of a project management system.

Within the engineering community, project management evolved out of the specialized activity of *project engineering*. Individuals who occupy a position as a project engineer work with a group of other engineers who support the project. In such situations questions of authority and responsibility are often raised when the project engineer becomes dependent on other people over whom he has limited control. Project management is inherent in engineering management. Those persons who aspire to engineering management positions should develop a working knowledge of project management.

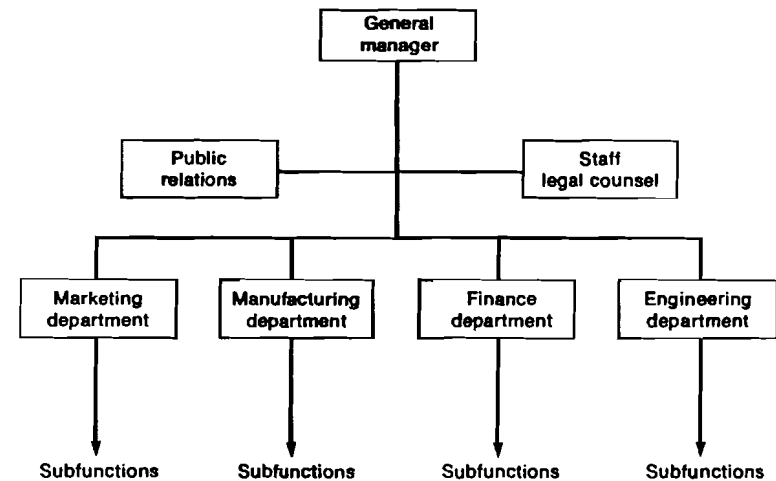
Project management is usually viewed as a technique for aligning organizational resources around the specific task to be done. For example, an engineering department that is designing a hydroelectric turbine generator system for an electric utility would organize a team of engineers to carry out the systems engineering work required for the generator system. A project manager would be appointed who would organize and develop a team of technologists to work on the project. By working with resource managers in the organization, an interdisciplinary team would begin the design of the system. A matrix type of organization would come into existence.

THE MATRIX ORGANIZATION

The matrix organization is the offspring of the marriage of the traditional functional organization and the interdisciplinary team formed to manage the project. Before describing the matrix organization in more detail, we should examine the nature of the most common type of organization structure in use in industry.

THE FUNCTIONAL TYPE OF ORGANIZATION

The most common form of organizational structure in American industry is the functional type, where personnel and resources having a common function are integrated as an entity in the organization. A functional organizational form is illustrated in Fig. 2.1. The general manager is responsible for establishing organizational objectives such as sales volume, profitability, growth, etc. These are translated into specific goals in each of the functional departments. The marketing department translates the goals into terms of a product most likely to achieve overall organizational objectives. The engineering department develops the hardware and software to support the organizational objectives; manufacturing is responsible for the actual production of the products that have been



Functional form of organization.

engineered and for the volume prescribed by the marketing department. The finance department translates organizational goals into financial measurements through establishing accounting procedures and standards and measuring the profitability of the organization.

The functional form of organization is normally used where standard products are found. In such an organization, contact with the customer is limited to the marketing and sales organizations. Coordination between the functional departments is typically done by the general manager or the department heads themselves, as needed.

A department manager takes the lead to coordinate activities when that department's work is critical to the solution of the current organizational problem. Such coordination is usually done on an informal basis.

The functional organization form is oriented toward established products and is not easily adapted to change. Consider the challenge faced by a manager who wishes to design, develop, and introduce a complex new product, particularly one that requires advancing the state of the art, is sophisticated, and is of key importance to the company. Such a product would require a substantial commitment of personnel and other resources in order to assure its successful implementation. An organizational form has to be established that is built around the product to be designed and developed. Such an undertaking requires an approach that can bring a focus to the product design and development activity. The general manager

34 must determine how to build the organization for the design, development, and introduction of the product in such a way that organizational resources can be integrated effectively without detracting from the ongoing production of established products.

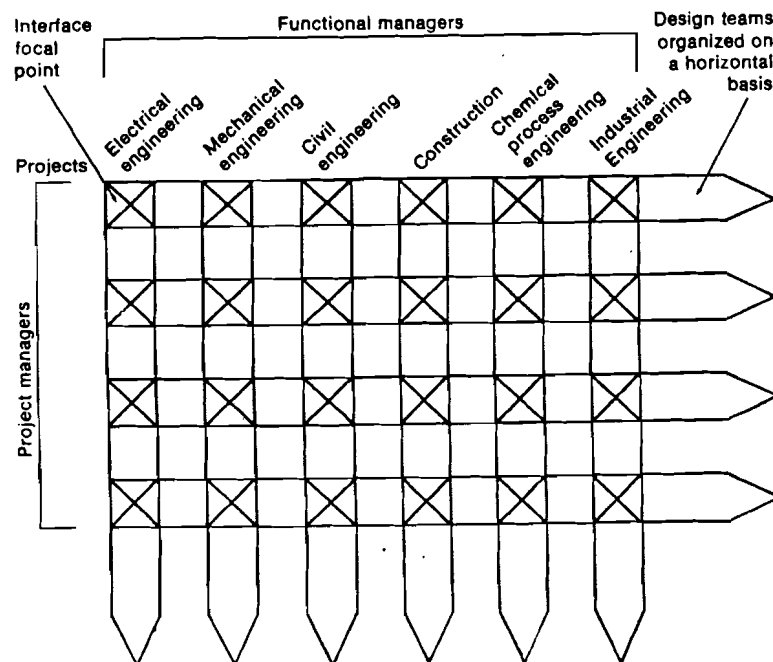
One solution that has been found successful in many diverse organizational contexts has been to establish a project, appoint a project manager, and build an organization centered around the design and development of the product. The resulting organizational form is a departure from the traditional functional organization. Such an organization is a matrix type.

NATURE OF THE MATRIX ORGANIZATION

The management of an engineering project requires an organizational arrangement that consists of a project team superimposed on the existing vertical structure of the organization. This can be illustrated by using the design of an industrial plant as a case in point, as shown in Fig. 2.2.

Matrix organization for engineering design of an industrial plant.

2.2



35 In this figure, the engineering personnel assigned to the design teams come from the different disciplines supporting the project. The interface of the vertical structure and the design team provides a focal point for pulling together the specialized engineering effort to support a project. The figure shows how these engineering disciplines and the engineering project teams interface in the matrix organization. "Interface" is used in the sense of coming together at common boundaries of interest in the management of the project activities.

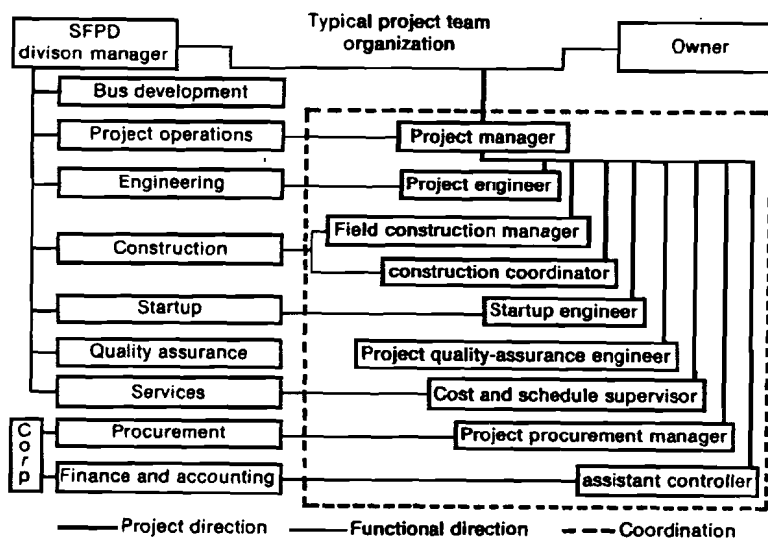
The management of the engineering project is handled through designating an individual as a *project manager* to provide an accountable focal point for pulling all needed organizational specialized interests into focus on the project. The focus of the specialized support on the project comes together in terms of an *authority-responsibility matrix*—hence the term "matrix organization."

The organizational model reflected in Fig. 2.2 is used to represent this authority-responsibility matrix. In this figure the specialized functional groups—the engineering disciplines—interface with the projects as organizational resources are applied to these projects.

Each project is headed by a project manager, who is a manager in the truest sense of the word. He is responsible for the planning, organizing, motivating, directing, and controlling of the organizational resources to be applied on a project. In such a role the project manager works with the specialized interest groups—the functional managers. A horizontal organization comes into being in such an organizational setting; the basis is thus formed for the matrix organization.

One characteristic of the matrix organization is that each person has two bosses—a project manager and a functional manager. On the surface this appears to be a violation of the management principle of *unity of command*, i.e., an individual should receive orders from only one superior. Consistent with the principle of unity of command is another well-known management principle: *parity of authority and responsibility*. This principle holds that authority and responsibility must be equal for a manager. When viewed in terms of the matrix organization, these principles have a particular significance. In such an organization the functional manager shares his authority with the project manager. The project manager is responsible for the completion of the project on time, within budget, and satisfying the objectives of the project. The functional manager has the responsibility of providing the specialized resources to support the project; the functional manager also tends to retain administration over the people who are assigned to him but who are working on the project.

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2.3

Typical project team organization. (From Frederick A. Hollenbach, "The Organization and Controls of Project Management," in *Realities in Project Management, Proceedings of the Ninth Annual International Seminar/Symposium, Project Management Institute, Chicago Oct. 22-26, 1977, p. 15.*)

EXAMPLES OF THE MATRIX ORGANIZATION

In the Bechtel Power Corporation a matrix organization form has emerged. This emergence has come about in response to the need to designate an individual as a leader of a key group of project people on complex projects who work on a particular construction effort. Such a key group of people includes a project engineer, field construction manager, construction coordinator, procurement manager, cost-schedule supervisor, quality assurance engineer, controller, and startup engineer. Figure 2.3 shows a typical project team organization in the Bechtel Power Corporation.

In the organizational model shown in Fig. 2.3 the project manager provides direction, integration, and synergy of the project team: "He represents the overall project and this is the focal point for the client and the project organization. He is an extension of the division manager for a project. He is the direct communications link between the client and the corporation, and establishes the appropriate channels of communication between the client's organization and both engineering and construction."³

³Frederick A. Hollenbach, "The Organization and Controls of Project Management," in *Realities in Project Management, Proceedings of the Ninth Annual International Seminar/Symposium, Project Management Institute, Chicago, Oct. 22-26, 1977, p. 15.*

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In such an organizational setting the project manager has three major goals relative to the project: to keep the project within budget, to keep it on schedule, and to ensure that it is acceptable to the client and to the corporation.

In Kaiser Engineers, the project manager's role is described so that he has responsibility for all facets of a major project. This responsibility includes the general facets of a turnkey project—engineering, design, procurement, and construction—as well as economics, market analysis, financing, and other such services. It is particularly significant to note the broad organizational context in which this company views its project managers:

The present-day project manager performs his duties in an ever more complex environment. He must be a true professional. He must address many new dimensions in today's projects, such as the public awareness and governmental relations factors. We are all familiar with the delays which are caused today by resistance by special interest groups, involvement in the courts, the multiplicity of new regulations and guidelines, and the complications of international politics and government-to-government relationships. Today, these factors take on the same degree of importance to the success of the program as many of the fundamental technical skills.⁴

Other uses of matrix organization that are not necessarily project-related are found in many contemporary organizations. Companies have experimented with variations of the matrix organization in dealing with different types of complex business situations. The typical diversified international corporation uses a matrix organization for the integration of product, function, and geographical activities to maintain a balance of management in the corporation's international operations.

Some companies use a variation of the matrix organization in which primary operational responsibilities are divided between "business managers," who are usually profit-center managers, and "resource managers," who provide the logistic support needed to carry on the business. Under this arrangement peer managers share strategic and operational decisions; reporting relationships for subordinates includes dual reporting to both the business manager and the resource manager.

It is not our intent to pursue the matrix-organization concept beyond its use in project-oriented activities.⁵

⁴V.E. Cole et al., "Managing the Project," in *Realities in Project Management, Proceedings of the Ninth Annual International Seminar/Symposium, Project Management Institute, Chicago, Oct. 22-26, 1977, p. 57.*

⁵For a good description of the matrix organization in a generic context, see Allen R. Janger, *Matrix Organization of Complex Businesses*, The Conference Board, New York, 1979.

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AUTHORITY AND RESPONSIBILITY IN THE MATRIX ORGANIZATION

The confluence of the stream of authority and responsibility relationships within the matrix organization raises such issues as "who works for whom?" More specifically, the workings of the matrix organization pose questions such as:

- 1 *How will the separate engineering disciplines be integrated into a systems approach?*
- 2 *Who will be responsible for the assignment of professionals on a particular engineering project?*
- 3 *Where will the work be done?*
- 4 *How much funds are available to be expended on the project?*
- 5 *What is to be done in the project by way of attaining project objectives?*
- 6 *How well has the work been accomplished on the parts of the project? On the entire project?*
- 7 *When is the work to be accomplished?*
- 8 *Why is the work being accomplished?*

Obtaining the answers to these kinds of questions in an authority-responsibility context has to be done from the perspective of *both* the project manager and the functional manager. These two managers play complementary roles as they manage resources supporting the projects. Their complementary roles are depicted in Table 2.1.

Complementary roles of project manager and functional manager in the matrix organization

2.1	PROJECT MANAGER	FUNCTIONAL MANAGER
1	<i>What is to be done in the project by way of attaining project objectives?</i>	1 <i>How will the engineering disciplines be integrated into the project?</i>
2	<i>How well has the work been accomplished on the project?</i>	2 <i>Who will be responsible for assignment of professionals on the project?</i>
3	<i>When is the work to be accomplished?</i>	3 <i>Where will the work be done?</i>
4	<i>Why is the work being accomplished?</i>	4 <i>How much funds are available for work assigned?</i>
5	<i>How much funds are available to support the project?</i>	5 <i>How well has the functional work been accomplished?</i>

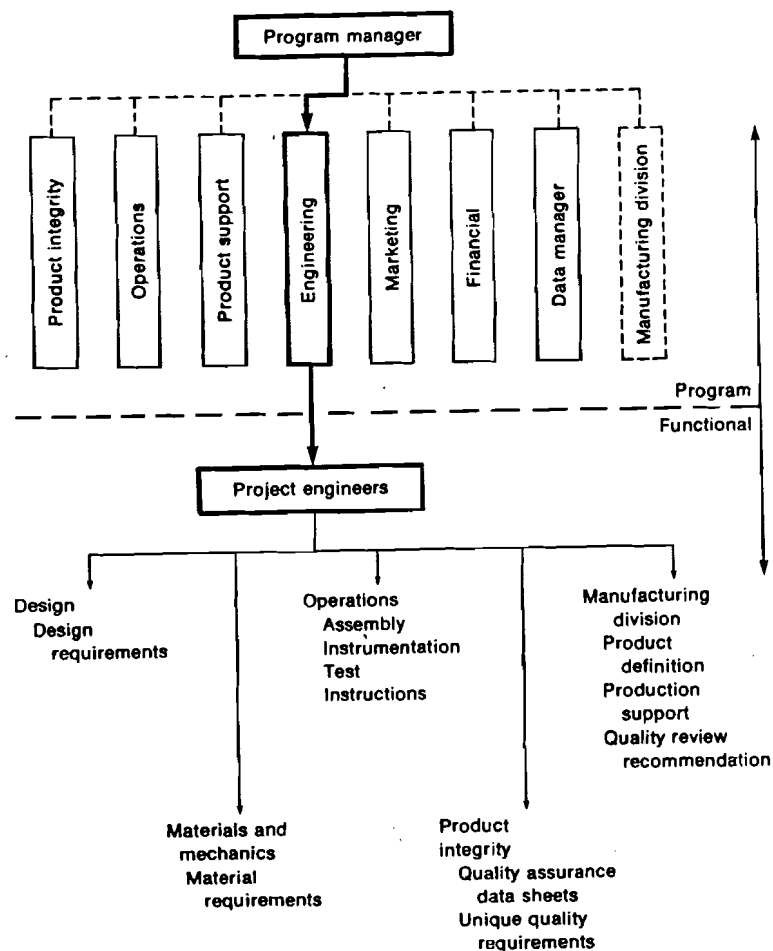
Authority and responsibility relationships

WHAT, WHEN, HOW MUCH	WHO, HOW		2.2
PROJECT MANAGER	DESIGN MANAGER	DESIGN ENGINEER	
Lead scoping activity for proposed projects Inside Outside	Participate in development of project plans	Prepare detailed plans and schedules for design tasks consistent with overall project plan, including initial definition of support requirements	
Represent project objectives to contributing functions	Participate in determination of project resource needs	Execute design tasks	
Cost Schedule Performance	Define design workload	Represent design engineering on project teams, in project reviews, for cost estimates, etc.	
Lead project teams	Assign design personnel, consistent with project needs	Communicate	
Project Definition Project Schedules Guidance & Direction	Maintain technical excellence of resources		
Ensure allocation of supporting resources	Recruit, train, and manage people in the organization		
Integrate and communicate project information	Assess quality of design activities		
Project Planning Council Product Board Outside	Provide technical guidance and direction		
Track and assess progress against plan	Communicate		
Resolve conflicts			
Communicate			

In Table 2.2 the relative roles of a project manager, a design manager, and a design engineer are shown. This example is taken from the engineering division of a large home-appliance manufacturer. The development of Table 2.2 within this company required many meetings of the people affected by the changing patterns of authority and responsibility portrayed in the table. Note the emphasis placed on *communication* as a responsibility of all participants in this organization.

Within an engineering organization, a project engineer works with a team of people from the engineering specialties involved. The design and development of a product is basically a technical process in which engineering has the leadership role, a role that is illustrated in Fig. 2.4, which shows an aerospace program manager's organizational relationship with project engineers in the design and development process. In this context, project engineering directs

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2.4

Role of project engineer. (Design/Development Process Guide, Subsystem Guide 3-3, Pratt & Whitney Aircraft Group, Government Products Division, United Technologies Corporation, p. 9.)

all technical aspects of the design and development process and is the program management arm of the engineering department.

There are few things that the project managers can do alone. They must rely on the support of many engineering specialists to bring their knowledge and skills to the project work. The specialists will usually have an administrative reporting relationship to their

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immediate supervisor, such as a section manager. The section manager provides administrative support to the engineers, submits merit evaluations on them, and is responsible for their career development. The project manager provides an organizational focal point for overall project planning, direction, and control. This focal point is based on the work packages of the project.

THE WORK-PACKAGE CONCEPT

The complementary roles of the project manager and the functional manager center around the work to be accomplished—the work package. A *work package* is an integral subelement of the project; a subsystem; a subproduct. Figure 2.5 shows the integral work packages with the component parts of a hydroelectric plant. Each part, e.g., intakes, power house, dam, control panel, can be thought of as a work package.

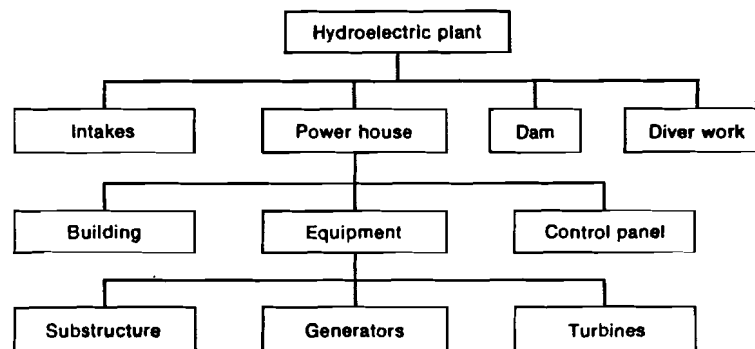
A work package grows out of a work-breakdown analysis that is performed on the project. When the work-breakdown analysis is completed and the work packages are identified, a work-breakdown structure comes into existence. A work-breakdown structure can be represented by a pyramid similar to that used for describing the traditional organizational structure. Stated another way, the work-breakdown structure represents the breakdown of the project objectives.

The work package that results from the work-breakdown analysis provides the basis for managing the project. Figure 2.6 illustrates that the basis of the matrix organization is the confluence of the project and the functional efforts.

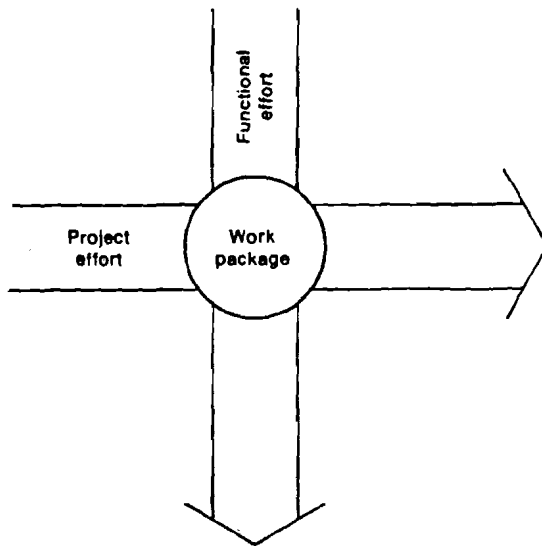
In the context of an engineering project, the work-breakdown analysis and the resulting work packages provide a model of

Hydroelectric plant showing integral work packages.

2.5



021



2.6

Confluence of the project and functional effort around project work package.

the products (hardware, software, services, and other outputs) that completely define the project. Such a model enables project engineers, project managers, functional managers, and general managers to think of the totality of all products and services comprised in the project. This model then can be used as the focus around which the project is managed—reporting progress and status of engineering efforts, resource allocations, cost estimates, procurement actions, etc. More particularly, the development of a work-breakdown structure with accompanying work packages is necessary to accomplish the following actions in the management of a project:

- 1 Summarizing all products and services comprised in the project, including support and other tasks
- 2 Displaying the interrelationships of the work packages to each other, to the total project, and to other engineering activities in the organization
- 3 Establishing the authority-responsibility matrix organization
- 4 Estimating project cost
- 5 Performing risk analysis

- 6 Scheduling work packages
- 7 Developing information for managing the project
- 8 Providing a basis for controlling the application of resources on the project
- 9 Providing a reference point for getting people committed to support the project

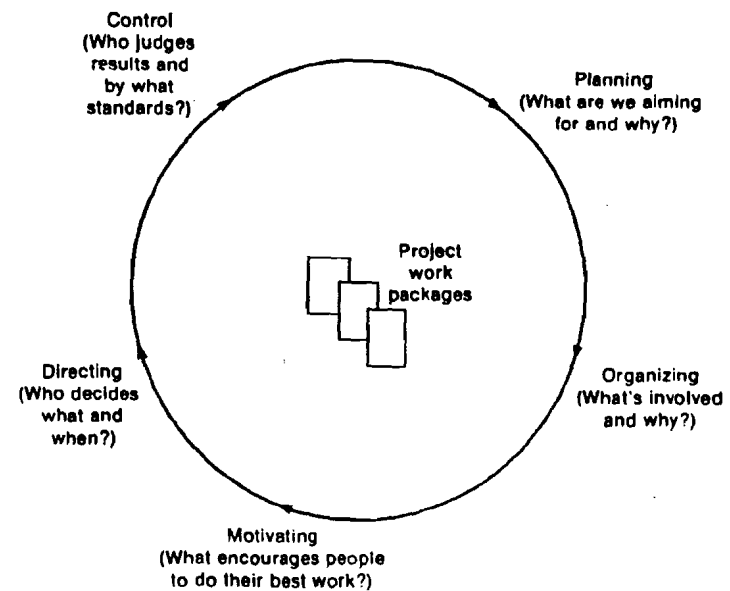
Each of these actions requires explanation; this explanation is given elsewhere in the text. This chapter is addressed to building the matrix organization and motivating people to support the project.

THE PERSONAL-COMMITMENT FACTOR

The project manager carries out the normal functions of a manager: planning, organizing, motivating, directing, and controlling. The focus around which he carries out these functions is illustrated in Fig. 2.7 in relationship to the project work packages. Figure 2.7 is shown to highlight the importance of the work package with the project management process and the personal-commitment factor. In the matrix organization the management functions come to focus on the project work packages.

The project management process.

2.7



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How well people are committed to support the project can make the difference between success and failure of the project. The importance of having individuals committed to support a work package of the project cannot be overemphasized. One engineering manager described the importance of this commitment in the following manner:

A work package is a commitment made and agreed to by two individuals "eyeball to eyeball" so to speak. It is a personal thing and has nothing to do with charts, graphs, or other inanimate pieces of paper. You don't have to make any commitment you don't agree to—normally. In very unusual circumstances your boss, and only your boss, will make a commitment for you, but this is the exception, not the rule. Only the parties to the commitment may agree to a change or cancellation of the commitment.

Of course, this commitment presupposes that the necessary planning has been done, i.e., the tasks have been adequately defined so that the personal commitment can be made. The same engineering manager noted:

If you can't commit to what the other person is asking you for, then the two of you had better redefine the task in such a manner that a commitment can be made. "Time and Material" contracts cannot be successful without this agreement. If you don't have a clear understanding of what each party is committed to, the inevitable day will arrive when the "misunderstanding" surfaces and someone's reputation and integrity suffer. These "misunderstandings" are more typically "no understandings," i.e., the problems or definitions of tasks were difficult in the beginning so they were avoided or set aside like they didn't exist. A real commitment between the two parties eliminates the problem and allows a real project management to flourish.

The work-breakdown structure along with the work packages provides a common denominator or framework for monitoring performance, cost, and schedule throughout the life of the engineering project. As an allied benefit the work-breakdown structure is a convenient method of managing by exception, that is, it provides a focus for highlighting critical items or areas of the project that must receive prompt attention by the managers concerned.

So much of getting people committed to a project depends on their understanding of what is expected of them and how they are to work with other people. When engineers are first exposed to management they find that the management process is not nearly as or-

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derly as their engineering discipline. In fact they usually find that management is "messy," particularly in the people relationships; yet so much of the success of an engineering manager depends on how effectively he is able to work with other people—peers, associates, superiors, subordinates, etc. As one recently appointed engineering manager said to one of the authors:

It came as quite a shock to me to realize that my success as a manager was so dependent on what other people could and would do and how effective I was in working with them. It wasn't this way when I was an engineer; then my success depended on how effective I was as an individual working alone. Being a manager is so much different from being a technical person; one must not only be able to see the big picture but see how the parts and people relate and fit into the big picture.

My training as an engineer taught me to look closely at the technical details of the work. This was a form of myopia; my particular engineering discipline helped me to develop a form of tunnel vision. This presented no problem as long as I remained in engineering work.

I was an outstanding engineer—in fact so outstanding that I was promoted to be a manager of engineers. Now my future is in someone else's hands. Now if I don't produce by working through my staff I will be a failure. This is not a comfortable feeling.

One reason engineers find being a manager "messy" is because they usually do not take the time and apply effective techniques for determining the *specificity* of how people should relate to each other as they cooperate in some endeavor. Too often the engineering manager (and other managers as well) tries to understand these relationships by studying traditional organizational charts, job descriptions, policy manuals, and such kindred documentation. These means are inadequate for an understanding of complex organizational interfaces such as found in the scientific and engineering community.

CHARTING THE AUTHORITY-RESPONSIBILITY MATRIX

In the authors' experience the organizational aspects of project management—how people are expected to relate to each other—cause most of the difficulties encountered in adopting project management techniques. Organizing a matrix organization by simply changing the reporting lines on the organization chart is not enough. Further organizational definition is necessary, particularly in developing specific delineations of authority and responsibility.

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If an engineer were asked to determine the specific interfaces of hardware systems, he would doubtlessly set out very detailed specifications. These specifications would lay out reliability, quality, and maintainability criteria. Also, there would be data bases established to provide the justification for setting up tolerances, energy flow, mechanical intermeshing, and so forth. When the plan for the integration of hardware was finally laid out, the specifics of the hardware interfaces would be understood. Yet this same engineer, when faced with an organizational interfacing situation, would probably not have access to any tools that would help him to better define the organizational interfaces.

There are organizational development tools that can help to give insight into these organizational interfaces. A useful technique is the linear responsibility chart.

LINEAR RESPONSIBILITY CHARTING

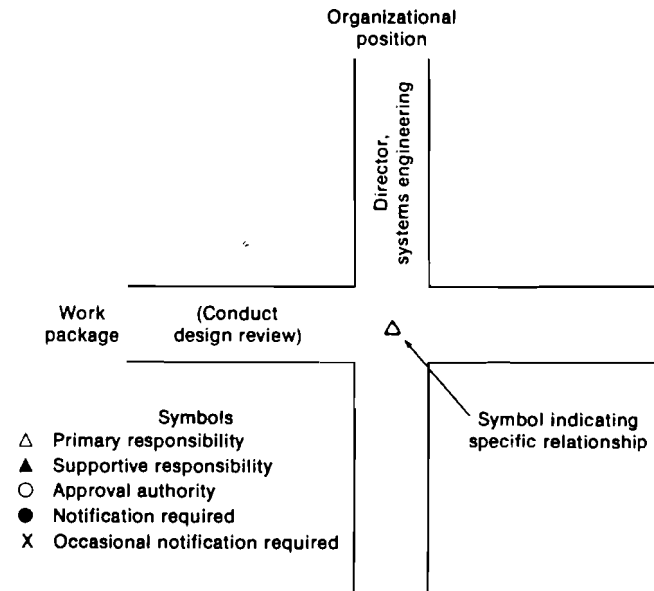
An alternative to the traditional organization chart is found in the *linear responsibility chart* (LRC), which goes beyond a simple structural display of the formal alignment of the organization. An LRC portrays the specific relationship of an organizational position and a task, or work package,⁴ to be accomplished. Figure 2.8 shows the essence of an LRC: (1) an organizational position; (2) a work package, in this case "conduct design review"; and (3) the symbol Δ , which indicates that the director of systems engineering has the primary responsibility for conducting the system design review. When several work packages are involved, one of the key advantages of using an LRC to establish organizational relationships becomes apparent, i.e., the people are brought into a dialog as to their specific authority and responsibility to a work package and to other individuals in the organization. Figure 2.9 shows an LRC for an organization involved in the design, manufacture, and delivery of an industrial system from the time of receipt of a firm order until the system is accepted by the customer. In this example, the organizational positions of manager of programs, information systems, and strategic planning have been added to the systems engineering position. The LRC depicts how these four positions relate to the work packages and to each other.

Project managers (sometimes called "program managers") report to the manager of programs in this example. The chart also helps to emphasize how the systems engineering manager has to work with many other people in the organization.

Perhaps the greatest value of the LRC is in the process of getting the people who occupy key positions together to discuss how

⁴The reader should understand that a work package can be something other than a piece of hardware. In Fig. 2.9 the management of the design, manufacture, and delivery of an industrial system is broken down into work packages.

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2.8

Model of a simple linear responsibility chart.

each position relates to other positions and to the work packages. In such meetings a dialog provides many opportunities to clarify working relationships, understand the other person's point of view, and in general, educate everyone on how things should be done in the organization.

An LRC can be viewed as an organizational plan; once the organization starts working on a project, the LRC serves as a control mechanism for ensuring that the people work on the right work package. Also, such a chart has a motivational effect on people, since it clarifies the formal work relationships and thus reduces the risk of interpersonal conflict. With the use of such a chart, people stand a better chance of knowing where they stand in the organization and what is expected of them.

DEVELOPING THE LRC

The development of the LRC is inherently a group activity, involving the key people in the organization who have some vested interest in the work that is to be done. If we take the situation that often faces an engineering project manager who is managing a project within an engineering department, we have a good example of the usefulness of

WORK PACKAGE	STRATEGIC PLANNING	INFORMATION SYSTEMS	SYSTEMS ENGINEERING	MANAGER OF PROGRAMS (PROGRAM MANAGERS)	OTHER
1 Program definition	●	●	▲	△	▲ Sales
2 Review and design define systems	▲	X	△	▲ ○	
3 Master schedule	X	▲	▲	△	▲ CA ● Field sales
4 Develop program budget		△	▲	▲ ○	● CA ▲ Sales
5 Funds allocation		▲		▲ ○	△ CA ▲ Sales
6 Define hardware-software work packages	X		△	▲	● CA
7 Define outside hardware-software work packages			△	▲	● CA
8 Schedule work packages		●	△	▲ ○	● CA
9 Schedule other work packages		●	▲	△	● CA
10 Define customer information requirements		●	▲	△	● ▲ CA
11 Conduct ongoing design review		X	△	▲	
12 Operate schedule tracking system		△	▲	△	▲ CA ▲ CA
13 Schedule review		▲	▲	△	▲ CA
14 Manage customer-initiated changes		▲	▲	△	▲ CA
15 Manage corporate-initiated changes		▲	▲	△	▲ CA
16 Develop startup plan		●	▲	▲ ○	△ Field service ▲ CA ▲ Field sales
17 Startup implementation		●	▲	△	▲ Field service ▲ Field sales
18 Warranty problems	X	●	△	▲	▲ Field service
19 Customer acceptance			▲	△	▲ CA
20 Out-of-warranty problems			▲	△	▲ Field sales

Code:

- △ Primary responsibility
- ▲ Support responsibility
- Notification
- Approval authority
- X Occasional notification

Other:

- Contract administration (CA)
- Sales
- Field sales
- Field service
- Installation and checkout

2.9

Linear responsibility chart: Design, manufacture, and delivery of an industrial system.

the LRC. In such a situation, the following plan for the development of an LRC should prove useful:

- 1 Distribute copies of the current traditional organization chart and position descriptions to the key people.
- 2 Develop and distribute blank copies of the LRC.
- 3 At the first opportunity, get the people together to discuss:
 - (a) The advantages and shortcomings of the traditional organization chart.
 - (b) The concept of a project work-breakdown structure and the resulting work packages.
 - (c) The nature of the linear responsibility chart, how it is developed, and how it is used.
 - (d) A way of establishing a symbology to show the work-package-organizational-position relationship. Getting a meeting of the minds on this symbology is very important so that the people will be willing to commit themselves to such a relationship.
 - (e) The makeup of the actual work-breakdown structure with accompanying work packages.
 - (f) The fitting of the symbols into the proper relationship in the LRC.
- 4 Encourage an intensive dialog during the actual making of the LRC. In such a meeting people will tend to be protective of their organizational territory. The LRC by its nature requires a commitment to support and share the allocation of organizational resources applied to work packages. This commitment requires the ability to communicate and decide. The process simply takes time. But it is worth the effort: when the LRC is completed, the people are much more knowledgeable about what is expected of them.

Even though the LRC can be of great assistance in helping to clarify personal and organizational interfaces, the *commitment* of people to support the project is vital. It is in the planning stages of a project that this commitment becomes so important. One manager emphasized this commitment in the context of project planning by noting that "the project plan is simply the summation of all of the individual commitments reached between the project manager and the functional managers. If the project manager... does not have these commitments, he is in no position to make a commitment on behalf of the Division. Remember, no one can commit you but yourself. Like-

wise, if you ever serve as project manager, *you* cannot commit anyone else."

Those engineers who aspire to be project managers should note the importance of this commitment idea. A good way to start is to ask themselves: Am I fully committed to those projects I am currently supporting? Have I provided the kind of personal commitment to the project manager that I would like if I were a project manager? Have I helped to develop an environment in the project work that is conducive to accomplishing the project objectives on time and within budget?

Much of the success of project management depends on how effectively the people work together to accomplish project objectives and gain personal satisfaction. Gaining this satisfaction can be related to how the people—the social groups—feel about the way in which project management is being practiced in the organization. The emotional patterns of the social groups—peoples' perceptions, attitudes, prejudices, assumptions, experiences, and values—determine the organization's "cultural ambience." This ambience in turn influences how people act and react, how they think and feel, and what they say in the organization, all of which ultimately determines what is taken for socially acceptable behavior in the organization.

THE CULTURAL AMBIENCE OF PROJECT MANAGEMENT

The success of project management may be less sensitive to the specifics of the organizational system than it is to the cultural ambience that exists in the organization. From a sociological viewpoint, a culture develops from the social and intellectual patterns within a group of people having a degree of common purpose, goals, language, customs, mores, and traditions. In its organizational context, a cultural ambience for project management deals with the social expression manifested by the participants engaged in managing projects. Within such organizations a culture emerges that reflects certain behavioral patterns characteristic of the members of that organization. Such behavioral characteristics influence the attitudes and the modus operandi of the people. A project team is made up of many participants in different organizational roles—superiors, subordinates, peers, associates—all working together to bring a project to completion. The cultural ambience that ultimately emerges is dependent upon the way participants feel and act within the matrix organizational environment.

An organization's cultural ambience is not just the people involved. It is the people united through policy, plans, procedures, formal and informal organizational relationships for the purposes of accomplishing project objectives through a matrix structure. The in-

tended formal relationships of the matrix organization are portrayed in organizational charts, project management manuals, job descriptions, policies, plans, procedures, and such documentation. This documentation is developed to establish the formal way of doing things in the organization.

There are other cultural forces that are not explicitly stated in any formal documentation and that emerge through the informal organization. In the cultural sense, these informal ways of doing things help to develop or inhibit a particular behavior on the part of the people. This behavioral attitude is often demonstrated by the statement: "Well, this is just the way we do things around here."

This cultural ambience reflects the prejudices and modus operandi of key people in the organization, both those who hold formal leadership roles and those who have emerged as informal leaders, able to influence others through their personal charisma, knowledge, expertise, interpersonal skills, social ties, etc.

The cultural ambience for project management is important, because it ultimately determines what is to be accomplished and how it will be done. This ambience affects the manner in which decisions are made and implemented in the matrix organization.

A descriptive summary of the cultural ambience conducive to successful project management reflects factors such as the following:

A consensus approach to decision making through which the project participants actively contribute in defining the question or problem as well as designing courses of action to resolve problems.

An explicit formal model of matrix organizational relations, which delineates the formal authority and responsibility patterns of the project managers, general managers, functional managers, and others working on the project.

An adversary role, which is assumed by any project participant who senses that something is wrong in the management of the project. Such an adversary questions goals, strategies, and objectives and asks the tough questions that have to be asked during the management of a project. A spontaneous adversary role can provide valuable checks and balances to guard against decisions that are unrealistic or overly optimistic. A socially acceptable adversary role facilitates the rigorous and objective development of data bases on which decisions are made.

An actual participation of people in the management of the project. They allocate their time to it and become ego-involved in planning for and controlling the project resources. As active participants in the project deliberations, they are quick to

suggest innovative ideas for improving the project or to sound the alarm when things do not seem to be going as they should.

A tendency toward flexible organizational structure and flexible lines of authority and responsibility defining that structure. There is much give-and-take across these lines, with people assuming an organizational role that the situation warrants rather than what the position description says should be done. Authority in such an organizational context gravitates to the person who has the best credentials to make the judgment that is required.

A project manager who is more of a facilitator than an active manager of people. He carries out the management functions of planning, organizing, and controlling by seeing to it that the necessary decisions are made and that strategies are designed for the implementation of decisions in the project. He facilitates an environment for the participants on the project to work together with economic and social satisfaction.

A process to resolve conflicting organizational policies and procedures. Conflict inevitably arises over the allocation of resources among the various projects. This conflict arises out of the nature of the matrix organization, because the participants view problems and opportunities from the perspective of their organizational loyalties. Since there is a process to resolve this conflict, participants know that they will have their "day in court" to negotiate for the scarce resources.

It may well be the cultural ambience of the organization that finally determines whether or not project management will work effectively. An important part of that ambience is the way in which the participants perceive the nature of project management as it is being carried out in the organization.

Project management techniques can be applied to many different types of projects, ranging from a large project such as the Alaska oil pipeline to small research and development projects.

We tend to think of project management in the context of doing something for a customer outside of the company. Project management techniques can be used effectively within a company when the matters to be managed require the use of a focal point to pull things together and to coordinate all the project activities. In this case the customer may be another manager who has a demand for the delivery of a project on time, within budget, and satisfying the operational objective.

ALTERNATIVE USES OF PROJECT MANAGEMENT

In one large United States corporation, the research and development laboratory is organized along project management matrix lines. Each R&D project has a project manager; in some cases a functional

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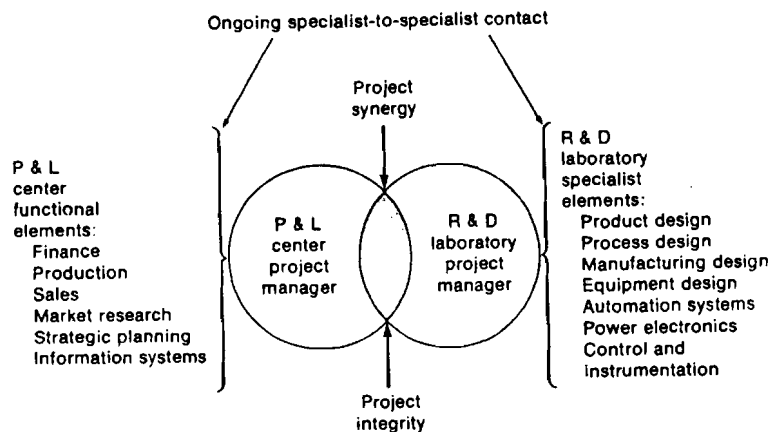
or department manager may also serve as a project manager on some development project. These project managers have a project team in the R&D laboratory that provides specialized support to the project. This corporation is organized on a profit-and-loss-center basis; each P&L center buys research and development support from the corporate R&D laboratory. Each P&L center has a P&L center project manager having complete responsibility for the project. Specialized resources of the R&D laboratory are committed to the P&L center project manager by the R&D laboratory project manager. The R&D laboratory manager commits to the scope and objectives of the project, as specified by the P&L center management. The P&L center management is kept informed of the project's progress to the level of detail desired through periodic design and status reviews as the project is carried out.

This type of intracorporate organizational arrangement is used for evaluating emerging strategic projects that require conceiving, prototyping, designing, and building unique, or first-of-a-kind, industrial systems.

Emerging strategic projects are so important to a profit-and-loss center and so complex to manage that the P&L center has to draw on the research and development laboratory resources to support the project. An intracorporate project management system evolved to serve this need; Fig. 2.10 illustrates this arrangement. The

Relationship of intracorporate project managers. Each project manager functions as an integrator-generalist responsible for ensuring project synergy. Each project manager is dependent on the other as they manage their respective project activities.

2.10



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P&L center appoints a project manager to manage all aspects of the project within the P&L center as well as work with a project manager in the R&D laboratory who manages a project team in the laboratory. Technical guidance is provided to the P&L center project manager by the R&D technical and management personnel; all overall decisions on the project are made by the P&L management team. Engineers, technicians, and draftsmen are assigned to work on the R&D project with the cost being borne by the customer—the P&L manager. The P&L project manager is furnished technical reports along with cost and schedule information in order that project visibility is maintained by such manager.

A pair of important advantages results from this organizational arrangement:

Corporate research and development resources are brought into focus to support the profit-and-loss center need.

The profit-and-loss center project manager facilitates the introduction of technology into strategic projects by virtue of his image as a local sponsor, i.e., a member of the P&L center staff.

Sometimes project management is used to develop new-business opportunities. Osgood and Wetzel have developed the concept of using project teams to identify such an opportunity and turn it into a viable business. According to them "the team would have direct decision-making responsibility for taking a new venture through the initial start-up stages, then gradually transferring this responsibility to administrative managers as the business approaches operating stability."⁷

Project management should be used only when necessary. The matrix organization is a complex way of organizing engineering resources. Each engineering manager should think about the development of criteria for determining when project management techniques are to be used in the organization.

WHEN TO USE PROJECT MANAGEMENT

Project management is not a panacea; it should be used only when its advantages are clear. Usually project management techniques are used in those engineering management situations where management attention is needed to focus attention on, to highlight, or to emphasize the importance of a particular engineering task. Such an activity might be restricted to a particular subfunction of engineering or be related across several functions. One company that

⁷William R. Osgood and William E. Wetzel, Jr., "A Systems Approach to Venture Initiation," *Business Horizons*, October 1977, p. 42.

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introduced project management techniques in its product-line engineering group defined a project in the following manner: "A narrowly defined activity which is planned for a finite duration, with a specific goal to be achieved (such as a new-product introduction). When the project is successfully completed, the project will be terminated."

The use of project management techniques can be considered for a wide variety of engineering management tasks. Criteria to be applied in determining whether or not to organize a project include such factors as (1) magnitude of the effort; (2) unfamiliarity of the undertaking; (3) interrelatedness of the tasks of the effort, and (4) the organizational reputation that is at stake in the undertaking.⁸

An important reason for developing criteria for using project management is to help in understanding some of the systems effects that occur.

THE SYSTEMS EFFECT OF PROJECT MANAGEMENT

When project management is introduced into an organization, a systems effect results. For example, what might appear on the surface to be an organization change when the matrix organization is set up soon becomes something larger. As the formal reporting relationships of the matrix organization are defined, new informal social relationships will emerge. The effective management of a project requires timely and relevant information. Most business systems are set up to provide information following the established organizational lines. When projects are established, the business systems have to realign the information so as to provide the project manager with adequate visibility of the schedule, cost, and performance parameters of the project.

In an industrial organization known to the authors, project managers were being held responsible for the timely accomplishment of project goals. However, the business-systems activity of the firm was not organized to accommodate and portray the information needed to evaluate schedule, cost, and technical performance of the ongoing projects. In self-defense the project managers developed their own crude information systems. Unfortunately, the data these information systems provided were insufficient, were tardy, and had little *predictive* value. As might be expected, these project managers never really knew how things stood. The result: schedule slippages, cost overruns, unreliable technical-performance evaluations, and general customer disenchantment. Fortunately, this problem was quickly turned into an opportunity through the development of an information retrieval system that was tailored to the project manager's needs.

⁸For a further discussion of when to use project management techniques, see David I. Cleland and William R. King, *Systems Analysis and Project Management*, 2d ed., McGraw-Hill, New York, 1975, Chap. 9.

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The management functions of planning and control of a project require approaches different from those that would be used if project management did not exist. The use of project selection techniques and project control measures are some additional systems effects of using project management. The next chapter will discuss in more detail the life-cycle concept of project management and how management techniques can be developed to accommodate the systems effects of project management.

SUMMARY

Project management is a way of bringing organizational resources into focus to support an ad hoc organizational activity such as an engineering project. Taken in its total context, project management is an activity that affects organizational couplings, information flows, management functions and techniques, and the cultural ambience of the organization itself.

Project management systems is an idea whose time has come. Engineering managers should develop a conceptual knowledge of the project management process and techniques.

DISCUSSION QUESTIONS

- 1 What do you consider the major drawbacks of the functional organization? Its major strengths?
- 2 Outline your understanding of the project management organization.
- 3 Can program management be effected without a matrix organization? Discuss.
- 4 Select an engineering process with which you are familiar. Identify and describe its work packages.
- 5 Cultural ambience has been suggested as a key factor in determining the success or failure of a project. Why is this true?
- 6 Cite examples of situations or operations that would benefit from a project management approach.
- 7 What is the systems effect of project management?
- 8 Why is it important to accurately define the authority and responsibility patterns in the matrix organization?
- 9 The matrix organization is found in environments other than project management. Describe how it might be used in a different context.
- 10 The project manager and the functional manager have a com-

- 58plementary authority relationship. Defend or refute this statement.
- 11 What are some of the uses to which a work package can be put?
 - 12 Compare the advantages and disadvantages of the linear responsibility chart.

KEY QUESTIONS FOR THE ENGINEERING MANAGER

- 1 What opportunities exist in this organization for the practice of project management?
- 2 Is the cultural ambience of this organization such that project management would be successful?
- 3 What are the key organizational interfaces through which the engineering manager's job is carried out?
- 4 Is the management principle of unity of command being practiced in this organization? Why or why not?
- 5 Has the *specific* authority of the project manager vis-à-vis the functional manager been defined?
- 6 Has a policy document outlining the authority of the project manager and the functional manager been defined in the matrix organization?
- 7 Do the technical people in the organization understand the idea of the work package in an engineering context?
- 8 Is the use of a work-breakdown structure understood by key people in the organization?
- 9 What can an engineering manager do to encourage the professional engineers to become fully committed to support the project managers?
- 10 One of the greatest values of a linear responsibility chart is the dialog that takes place in completing the chart. Has this aspect of linear responsibility charting been fully put into practice?
- 11 How would the cultural ambience for project management be described for the organization?
- 12 Have criteria been developed for the time when project management will be practiced in the organization?
- 13 What are some of the systems effects that exist from having established project management in the organization?

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ENGINEERING 3

PROJECT

LIFE CYCLE

In this chapter we will develop the project (or system) life-cycle idea and discuss its phases. We will also describe some examples where the life-cycle concept has been applied in the engineering context. In our discussion, we will tend to use the terms "project life cycle" and "system life cycle" interchangeably. The life-cycle concept applies to both a project and a system—hence our tendency to interchange the terms.

Any system, whether hardware, software, biological, economic, etc., is dynamic. A system is created, develops, grows, reaches maturity, and may eventually decline and disappear. Product systems—such as a transportation system—go through years of detailed design and development before production. When the transportation system is finally put into operation, many years have elapsed since the emergence of the idea to develop it. A new drug will undergo approximately 10 years of development and testing before it can be sold to the customer. The requirement for registration and testing of the drug under the United States Pure Food and Drug Act has expanded the time required to bring a drug from the basic research stage to the marketplace. Engineering project managers in the construction industry are aware of the additional time required for the completion of construction projects since the passage of land-use laws and the requirement to file environmental impact statements. Virtually every industry has felt the growing impact of legislation affecting such areas as consumer protection, environmental impact, social security, etc., which serves to lengthen the time required to develop, design, produce, and place a system in its operational environment.

Every system has natural phases of development. Even the solar system had a beginning, perhaps a cataclysmic beginning. The seasons of the year, the growth of our children, the coming and going of institutions all serve to remind us how transitory systems are in this world of ours.

62 PHASES OF THE SYSTEM LIFE CYCLE

A system is an assemblage or combination of things—both abstract and concrete—and people for its realization. In this section, we present a generic model of a system life cycle that can be applied to many different situations to be encountered by the engineering manager. Such situations may include:

- Moving an engineering organization from one location to another
- Reorganizing an engineering department
- Managing an engineering project
- Managing a research project
- Analyzing the requirements for and obtaining capital equipment
- Managing a product-improvement engineering effort
- Studying a change in the quality and quantity of professional personnel
- Managing an engineering change
- Developing and building an energy management system

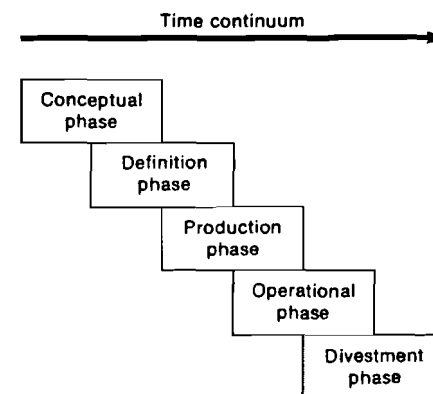
The phases of the life cycle—and what is to happen to the system during its life—depend on the distinctive characteristics of the system. The phases we have identified below serve only to represent a generic approach that can be taken by an engineering manager who plans to use this concept in his activities.¹ Figure 3.1 portrays a schematic model of such a life cycle. Note that the generic model in Fig. 3.1 and Tables 3.1 through 3.5 are intended to provide a broad philosophy of the notion of the life cycle applied to many engineering activities.

THE CONCEPTUAL PHASE

The germ of the idea for a system may evolve from other research, from current organizational problems, or from the observation of organizational interfaces. The conceptual phase is one in which the idea is conceived and given preliminary study and evaluation.

During the conceptual phase, the environment is examined, forecasts are prepared, objectives and alternatives are evaluated, and the first examination of the *objective*, *cost*, and *schedule* aspects of the system's development is performed. It is also during this phase

¹In describing the generic approach to a system life cycle, we have drawn heavily from David I. Cleland and William R. King, *Systems Analysis and Project Management*, 2d ed., McGraw-Hill, New York, 1975, as well as from public domain documentation developed by DOD and NASA.



3.1

Generic model of system life cycle.

that basic strategy, organization, and resource requirements are conceived. The fundamental purpose of the conceptual phase is to conduct a feasibility study of the requirements in order to provide a basis for further detailed evaluation. Indeed, the conceptual phase should provide the opportunity to "ask ourselves what questions we should be asking ourselves."²

If the conceptual phase is properly approached, it can serve to kill those projects which should not survive. There will typically be a high mortality rate of potential systems during the conceptual phase of the life cycle. This is rightly so, since the study process conducted during this phase should identify projects that have high risk and are technically, environmentally, or economically infeasible or impractical.

Some insight into the value a rigorous application of the conceptual-phase questions can have in sorting out ventures that should be eliminated is given in a recent *Business Week* article. Industry, according to *Business Week*, should learn how to weed out bad ideas early.³ To that end, the Dexter Corporation has instituted an eight-factor "innovation index" approach to research management that considers such factors as effectiveness of communications, competition, timing, etc., and comes up with an innovation potential for new ideas. Glaser describes the innovation index as a technique to evaluate the innovation of a project.⁴ According to Glaser: "If one must err, do it on paper—it's cheaper."⁵

²We have paraphrased Dr. Albert Einstein's famous remark.

³"Vanishing Innovation," *Business Week*, July 3, 1978, p. 461.

⁴See Chap. 5 for a description of this technique and the role that communication plays in making the technique work.

⁵Milton A. Glaser, "The Innovation Index," *Chemical Technology*, vol. 6, March 1976, pp. 182-187.

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What should be used as a standard yardstick or denominator against which to measure potential new systems in the conceptual phase? We believe there is only one such proper common denominator: *the basic purpose or mission of the organization*. The basic purpose should be described in the master plan for the organization. The length of a system life often extends many years into the future, and the timing of the project with respect to the basic purpose of the organization at some *future* time is a key factor in the evaluation.

In summary, the conceptual phase is important, since it sets the stage for asking a series of questions about the proposed idea vis-à-vis basic organizational objectives. Table 3.1 outlines some of the key issues that have to be dealt with in this phase.

THE DEFINITION PHASE

Once the system has survived the conceptual phase, the analysis of the system progresses to the definition phase. The purpose of the definition phase is to determine, as soon as possible and as accurately as possible, cost, schedule, performance, and resource requirements and whether all elements, work packages, and subsystems will fit together economically and technically.

The definition phase simply tells in more detail what it is we want to do, when we want to do it, how we will accomplish it, and what it will cost. This phase allows the organization to fully conceive

Conceptual phase

3.1	1	Determine existing needs or potential deficiencies of existing systems.
	2	Establish concepts which provide initial guidance to overcome existing or potential deficiencies.
	3	Determine initial technical, environmental, and economic feasibility and practicability of the proposed system.
	4	Determine compatibility of proposed system with the basic purpose of the organization.
	5	Examine alternative ways of accomplishing the system objectives.
	6	Provide initial answers to the questions: (a) What will the system cost? (b) When will it be available? (c) What will it do? (d) How will it be integrated into existing systems?
	7	Identify human and nonhuman resources required to support the system.
	8	Select initial designs which will satisfy the system objectives.
	9	Determine initial system interfaces.
	10	Establish an organizational approach.
	11	Make a specific decision to continue or discontinue the development of the system.

Definition phase

		3.2
1	Firm identification of the human and nonhuman resources required	
2	Preparation of final performance requirements	
3	Preparation of detailed plans required to support the system	
4	Determination of realistic cost, schedule, and performance requirements	
5	Identification of those areas of the system where high risk and uncertainty exist, and delineation of plans for further exploration of these areas	
6	Determination of necessary support subsystems	
7	Definition of intersystem and intrasystem interfaces	
8	Identification and initial preparation of the document required to support the system, such as policies, procedures, job descriptions, budget and funding papers, letters, memoranda, etc.	
9	Establishment of the compatibility of the system with the future basic purpose of the organization	
10	Design of prototypes	

and define the system before it starts to physically put it into its environment. Simply stated, the definition phase dictates that one stop and take time to look around to see if this is what one really wants before the resources are committed to putting the system into operation and production. If the idea has survived the conceptual phase, a conditional approval for further study and development has already been given. The definition phase provides the opportunity to review and confirm the decision to continue development, create a prototype, and go into production or installation.

Decisions made during the definition phase may also include the cancellation of further work on the system and the redirection of organizational resources elsewhere. The concerns and activities of this phase are described in Table 3.2.

THE PRODUCTION PHASE

After the definition phase of the project has passed and the system has been committed for production, the system progresses to the production phase. In this phase the system takes physical shape and form and is capable of taking its place in the environment.

The purpose of the production phase is to acquire and test the system elements and the total system itself using the standards developed during the preceding phases. The production process involves such things as the actual setting up of the system, the fabrication of hardware, the delineation of authority and responsibility patterns, the construction of facilities, and the finalization of supporting documentation. Table 3.3 details this phase.

During the production phase the inadequacies of the analysis conducted in the two preceding phases will come to light. Cost

Production phase

- 3.3**
- 1 Updating of detailed plans conceived and defined during the preceding phases, as well as conducting of field tests where applicable
 - 2 Identification and management of the resources required to facilitate the production processes, such as inventory, supplies, labor, funds, etc.
 - 3 Verification of system production specifications
 - 4 Design of final production components
 - 5 Beginning of production, construction, and installation
 - 6 Final preparation and dissemination of policy and procedural documents
 - 7 Performance of final testing to determine adequacy of the system to do the things it is intended to do
 - 8 Development of technical manuals and affiliated documentation describing how the system is intended to operate
 - 9 Development of plans to support the system during its operational phase

overruns, schedule slippages, or system performance deficiencies may appear. System performance inadequacies can be corrected through the judicious use of engineering changes—if such changes are managed properly. Such changes, however, usually impinge on the project's costs and schedule and result in the expenditure of additional resources.

A study conducted by the United States government gives a good indication of the magnitude of cost overruns in the acquisition of large systems.⁶ The report uses the following categories to identify cost escalation:

- 1 Quantity changes—including scope changes
- 2 Engineering changes—an alteration in the established physical or functional characteristics of a system
- 3 Support changes—involving spare parts, ancillary equipment, warranty provisions, and government-furnished property and/or equipment
- 4 Schedule changes—in delivery schedule adjustments, completion date, or some intermediate milestone of development, production, or construction
- 5 Economic changes—influence of one or more factors in the economy, such as inflation
- 6 Estimating changes—due to corrections or other changes occurring since the initial or other baseline estimates for program or project costs were made

⁶Final Status of Major Acquisitions. Report to Congress by Comptroller General of United States, June 30, 1975

7 Sundry—changes which do not fall within the above categories, such as environmental costs and relocation assistance for water and highway projects

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A cost-growth analysis for 120 projects, other than military weapons systems, is summarized in the accompanying table.⁷

Type of change	Energy Research and Development Administration	Army Corps of Engineers	Department of Transportation	Other civil agencies	Total changes
Quantity	\$ 215,610*	\$1,880,171	\$10,218,288	\$ 994,683	\$13,288,752
Engineering	501,910	1,832,666	19,870,574	485,006	22,690,176
Support	39,500	0	8,857	0	48,357
Schedule	88,940	11,865	-5,250	77,000	172,555
Economic	670,110	4,353,736	29,445,667	2,163,016	36,632,529
Estimating	209,090	406,742	370,538	199,386	1,185,756
Sundry	229,250	143,431	4,309,375	691,847	5,373,903
Total	<u>\$1,954,410</u>	<u>\$8,608,631</u>	<u>\$64,218,049</u>	<u>\$4,610,938</u>	<u>\$79,392,028</u>
Number having 100 % or more increase	7	78	15	20	120
Total civil projects	26	170	55	216	467

*Dollar figures in thousands.

A perusal of this data indicates that the principal factor in cost growth is the economic changes, chiefly inflation, which account for 46 percent of the total. Engineering changes account for 28 percent of the total. One can raise questions about the adequacy of the analysis conducted during the conceptual and definition phases. Would a more thorough analysis of these systems in these phases have helped to reduce subsequent cost (and schedule) overruns? We believe it would have helped a great deal.

The point is this: The conceptual and definition phases of a system life cycle provide an opportunity to analyze and design the project so that the question "Do we know what we are really getting into?" can be answered before a production commitment is made. And that is what these two phases are really all about.

THE OPERATIONAL PHASE

The fundamental role of the manager of a system during the operational phase is to provide the resource support required to ac-

⁷Ibid.

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comply system objectives. This phase indicates the system has been proven economical, feasible, and practicable and will be used to accomplish the desired ends. In this phase the manager's functions change somewhat. The manager is less concerned with planning and organizing and more concerned with controlling the system's operation along the predetermined lines of performance. His responsibilities for planning and organization are not entirely neglected—there are always elements of these functions remaining—but he places more emphasis on motivating the human element of the system and controlling the utilization of resources of the total system. It is during this phase that the system may lose its identity per se and be assimilated into the "institutional" framework of the organization.

If the system in question is a product to be marketed, the operational stage begins the sales life-cycle portion of the overall life cycle, for it is in this phase that marketing of the product is conducted. Table 3.4 shows the important elements of this phase.

THE DIVESTMENT PHASE

The divestment phase is the one in which the organization gets out of the business that it began with the conceptual phase. Every system—be it a product system, a weapons system, a management system, or whatever—has a finite lifetime. Too often this goes unrecognized, with the result that outdated and unprofitable products are retained, inefficient management systems are used, or inadequate equipment and facilities are put up with. Only by the specific and continuous consideration of the divestment possibilities can the organization realistically hope to avoid these contingencies. Table 3.5 relates to the divestment phase.

Even those engineering projects that have been "failures" can hold something of value in the sense of lessons learned from the experience. The evaluation of failures is usually neglected. However, if it is done properly and without any attempt to submit "report cards" on the people who are involved, the results can be helpful. Otherwise, "unless one learns from history, one is condemned to repeat it."⁸

⁸Hanson W. Baldwin, *Strategy for Tomorrow*, Harper, New York, 1970, p. 10.

Operational phase

3.4	1	Use of the system results by the intended user or customer
	2	Actual integration of the project's product or service into existing organizational system
	3	Evaluation of the technical, social, and economic sufficiency of the project to meet actual operating conditions
	4	Provision of feedback to organizational planners concerned with developing new projects and systems
	5	Evaluation of the adequacy of supporting systems

Divestment phase

1	System phasedown	3.5
2	Development of plans transferring responsibility to supporting organizations	
3	Transfer of resources to other systems, including transfer of technology	
4	Development of "lessons learned from system" for inclusion in qualitative-quantitative data base to cover:	
	(a) Assessment of image by the customer	
	(b) Major problems encountered and their solution	
	(c) Technological advances	
	(d) Advancements in knowledge relative to strategic objectives	
	(e) New or improved management techniques	
	(f) Recommendations for future research and development	
	(g) Recommendations for the management of future programs	
	(h) Other major lessons learned during the course of the system	

An evaluation of the management of projects that fail—that *do not accomplish what was expected*—is essential. Also, an evaluation of the management of successful projects can be useful. Such evaluation should be centered around the harmony of the results with the intended purpose reflected in a higher-level organizational plan. If the organization is successful in a particular business area, there is a strong tendency to continue research and development projects in that area. Drucker alludes to a real strategic danger in this respect when he comments, "It is far more difficult to abandon yesterday's success than it is to reappraise failure."⁹

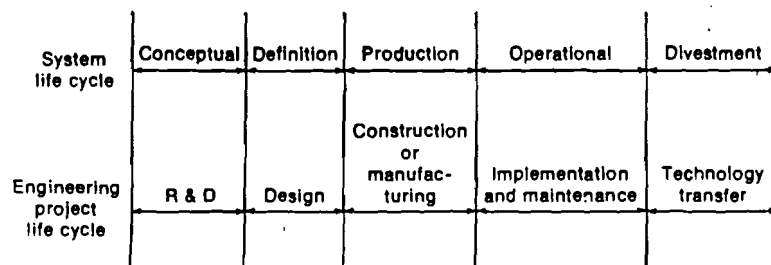
Taken together, Tables 3.1 through 3.5 provide an outline of the overall system life cycle. Of course, the terminology used in these tables is not applicable to every system that might be under development, since the terminology generally applied to the development of consumer product systems is often different from that applied to other systems. Both in turn are different from that used in the development of a financial system for a business firm. However, whatever the terminology used, the concepts are applicable to all systems.

For instance, the following phases are present in the life of an engineering project: (1) research and development, (2) design, (3) construction and manufacturing, (4) implementation and maintenance, and (5) transfer of technology. Figure 3.2 illustrates the correspondence between the terminology of the system life cycle and the phases identified for an engineering project. Each phase of an engineering project could itself be managed on a life-cycle basis.

It should be noted here that there are not necessarily one-to-

⁹Peter F. Drucker, *Management: Tasks, Responsibilities, Practices*, Harper, New York, 1973, p. 159.

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3.2

Life-cycle phases of an engineering project.

one relationships among the activities of the corresponding phases in the different terminology patterns. As an example, in a major engineering project with one main product—say, the construction of a mass transit system—the sale of the ultimate product should precede as well as be part of the research and development phase. Feasibility studies that are carried out in this phase invariably provide information for a go-no-go decision. If the project survives this phase and moves on to the next, then the potential customer must have been satisfied with the prospects for ultimate accomplishment of the project. In other words, the customer has bought the project.

This concept of a marketing activity at the outset of a project life cycle differs from the traditional view that marketing belongs to the operational phase. Both views are accurate provided one identifies the context in question.

To go one step further, a given undertaking need not formally go through all the life-cycle phases. Indeed, using feedback information from a previous process or system, it may be possible to skip both the R&D and design phases and to commence with the construction phase.

The use of a life-cycle approach is well established in the engineering community. The particular approach used depends on the type of engineering being carried out. Companies in the aerospace industry have developed highly sophisticated life-cycle models to use in managing the design and development process of their products. For example, one company envisions the design and development process of a gas-turbine engine for aircraft applications as consisting of six phases. The phases involve various steps to establish requirements, create and verify designs, qualify the design product, and support production engines during flight operations. The six phases of the design and development process with their purpose and output are shown in Table 3.6.

All the steps in each phase are conducted for a complete engine-development program. If the effort is less than a full develop-

The six phases of the design/development process*

PHASE	PURPOSE	OUTPUT	3.6
1 Conceptual	Understand customer needs Create conceptual designs Select best concept Demonstrate conceptual design	Conceptual design definition Conceptual design hardware Demonstrated conceptual design	
2 Initial design verification	Complete initial product design Verify modified product design concept	Initial product design definition Initial product design hardware Verified initial product design concept	
3 Product design	Modify initial design to incorporate verification test results Verify modified product design	Improved product design definition Improved product design hardware Verified product design concept	
4 Qualification	Develop engine through qualification	Qualified engine	
5 Initial operational	Introduce product into initial operation Identify and fix early problems	Operational aircraft PSP and CIP programs for problem solution	
6 Full deployment	Provide customer with full complement of operational aircraft Provide customer support for life of product	Full operational weapon system deployment Sustaining engineering PSP and CIP programs	

*See "Design/Development Process Guide, Subsystem Guide 3-3," Pratt & Whitney Aircraft Group, Government Products Division, United Technologies Corporation, p. 6.

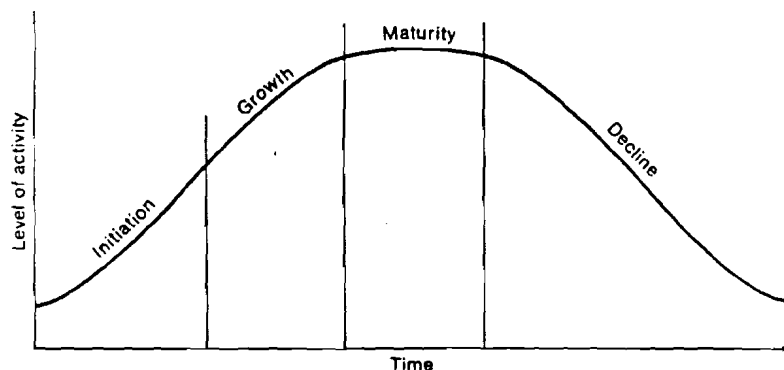
ment, only some of the steps would be appropriate. For example, a "technology contract" would involve only the first portion of the conceptual phase.¹⁰

LEVELS OF ACTIVITY

The phases discussed in the preceding pages are not mutually exclusive. Rather, they overlap. In addition, each phase goes through various levels of activity. There are four discernible groups of activity. They are initiation, growth, maturity, and decline of the phase. As indicated in Fig. 3.3, the levels of activity are highest during the growth and maturity periods.

¹⁰See "Design/Development Process Guide, Subsystem Guide 3-3," Pratt & Whitney Aircraft Group, Government Products Division, United Technologies Corporation, for an excellent description of the design and development process.

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3.3

Levels of activity in a given phase.

Of course, not all projects reach maturity. For example, in the research and development community the success of projects has been poor: about one of twenty programs initiated ever results in significant commercial success.¹¹

In those situations of successful products, research has shown an average elapsed time between the initial conception and a positive cash flow averaging 7 to 10 years.¹²

SOME APPLICATIONS OF THE LIFE-CYCLE CONCEPT

To illustrate the ubiquity of the life cycle in the engineering management context, subsequent portions of this chapter will cite some examples where the life-cycle concept is applied. The examples will illustrate the concept in different types of projects imbedded in one or more phases of the generic life cycle.

INDUSTRIAL DEVELOPMENT PROJECT

An oil company contracted for the construction of camp sites in Saudi Arabia. The company that managed and constructed these camp sites used a master life-cycle phasing chart as the basic approach for the planning and control of the construction. Table 3.7 contains the life-cycle chart with its major phases and work packages in each phase.

Of course, each of the work packages has subactivities or subsystem work packages, which in themselves can be dealt with on a life-cycle basis with attendant phases and activities.

¹¹P. L. Mullins, "Capital Budgeting for Research and Development," *Management Services*, May-June 1969, pp. 45-50.

¹²*Ibid.*

Life-cycle phases of camp site construction

				3.7
DEVELOPMENT	DESIGN	ENGINEERING AND CONSTRUCTION	OPERATIONAL AND MAINTENANCE	
Conceptual studies	Design	Estimating	Logistics	
Engineering economics	Drawings	Reporting	Facilities and maintenance	
Site planning	Specifications	Forecasting	Project control	
Environmental impact studies	Estimates	Analysis	Inspection	
Master planning	Bid packages and evaluation	Schedules	Feeding and housing	
	Budget analysis	Material control	Communications	
		Purchasing	Community services	
		Expediting	Transportation	
		Vendor inspection	Material and equipment	
		Traffic	protection	
		Subcontracts	Operator training	
		Construction planning and methods	Waste control and disposal	
		Constructibility reviews		
		Labor relations		
		Quality control		
		Field administration and engineering		
		Safety and first aid		
		Warehousing		
		Engineering:		
		Architectural		
		Civil		
		Electrical		
		Instrumentation		
		Mechanical:		
		Piping		
		Sanitary		
		Structural		
		Water supply		

RESEARCH AND DEVELOPMENT PROJECT

An R&D project goes through a life cycle from the idea stage to a prototype model—and, if it is meritable, on to full-scale production. Before a development project is undertaken, a reasonable degree of commercial risk is demonstrated. As the commercial cost-schedule parameters of the project are defined, a profile of the minimum technical parameters that are required will be delineated. At each stage of the R&D pipeline, a series of activities will proceed in parallel with the technical project development program work, such as:

Market feasibility studies

Legal and patent investigation

Financial analysis

Figure 3.4 shows an expanded research pipeline envisioned by Merrifield.¹³

NEW-PRODUCT DEVELOPMENT

The value of the life-cycle concept in the management of a project is demonstrated in the procedure used by a major industrial firm in its identification, development, and funding for new products and features. At appropriate intervals during the evolution of a process, a review is carried out to assess the status of the project and to recommend whether or not the project should continue.

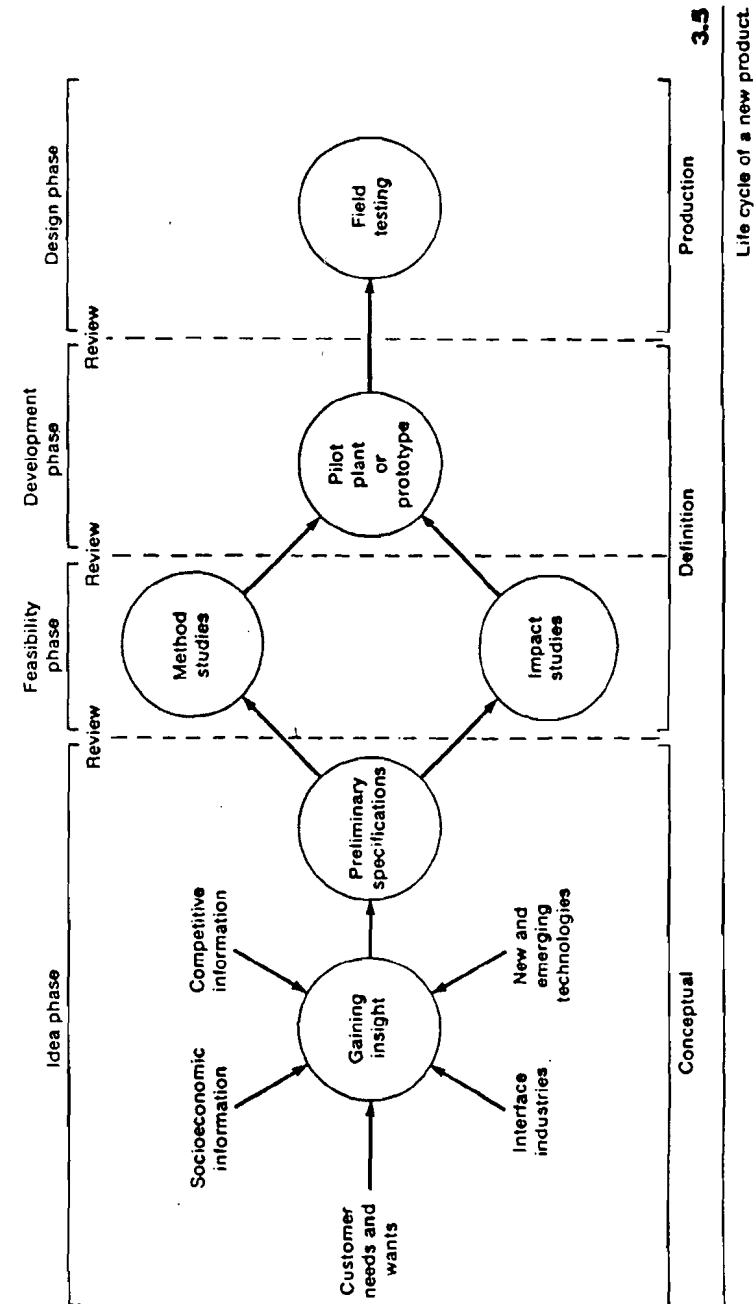
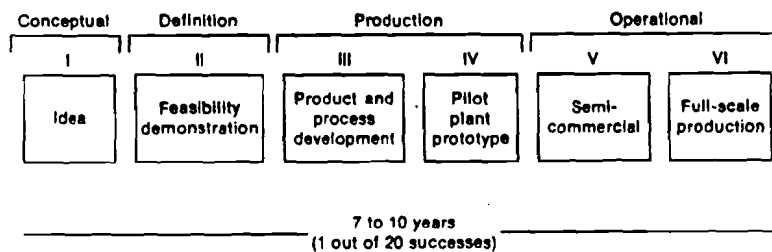
An "innovation team" gains insight and seeks opportunities for new products and features by continuously monitoring customer needs and wants, socioeconomic and competitive information, interface industries, and new and emerging technologies. Along with others, the innovation team then screens ideas for feasibility and ultimately develops general objectives and quality and costs (preliminary specifications) for the new product. At this point, the product planning council, consisting of engineering and financial managers, reviews the proof of feasibility.

If the evidence is convincing, different functional divisions of the organization then collaborate to search for alternative methods of producing the product within the constraints of the preliminary specifications, as well as examine the product impacts such as marketing prospects. A second product planning council review takes place at this stage. If the outcome is positive, a new-product development team is established.

¹³Bruce D. Merrifield, *Strategic Analysis, Selection, and Management of R&D Projects*, AMA Management Briefing, AMACOM, a division of American Management Associations, New York, 1977.

Stages of the research pipeline. (From D. Bruce Merrifield, *Strategic Analysis, Selection, and Management of R&D Projects*, AMACOM, New York, 1977, pp. 28-32.)

3.4



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The development team carries out pilot plant and prototype studies, and its efforts are subjected to yet another review. Success at this level then leads to the product design phase. A summary of these steps is given in Fig. 3.5, with the terminology of the generic life cycle included to underscore its direct correspondence with the new-product model under discussion.

CONSTRUCTION PROJECT

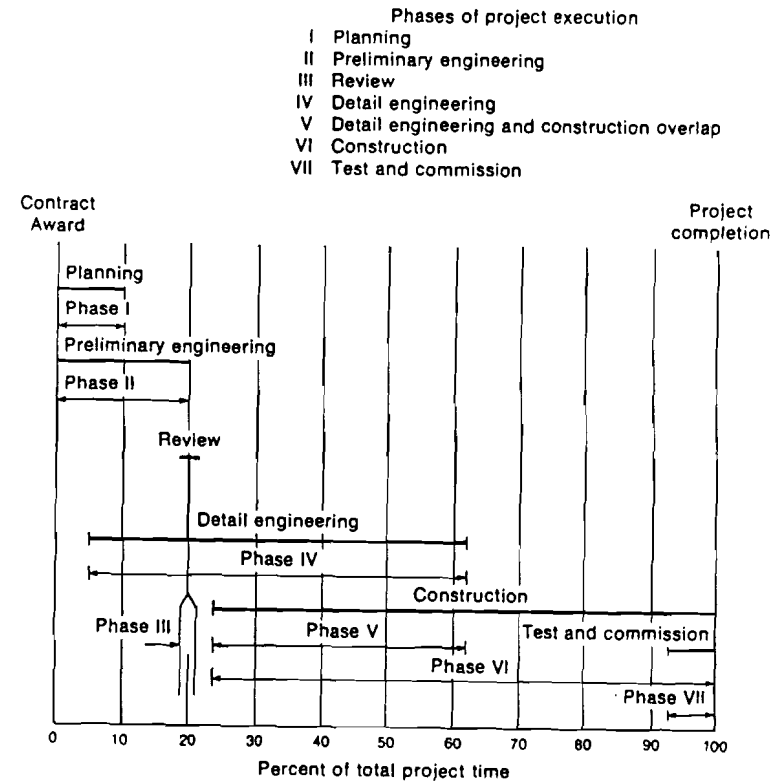
In Fluor Utah, Inc., a leader in executing engineering, procurement, and construction contracts, projects are divided into identifiable phases. Each phase contains a defined work function with a specific input and goal. As the project moves from phase to phase, the composition and talents of the people assigned to the project change. Figure 3.6 shows how these phases are arranged in a life-cycle relationship.

MANAGEMENT IMPLICATIONS OF THE LIFE-CYCLE CONCEPT

The concept of the life cycle has its greatest impact in contributing to the management of the project. Indeed, the management system for the project can be built around the model of the life cycle of the project. In this section some management implications of the life cycle will be discussed.

The importance of viewing engineering activities through a system life cycle can be illustrated by taking an engineering project and looking at it from a management perspective. An *engineering project* can be defined as any agreement to deliver an engineering product or service for a stipulated amount of money in a stated time. With this definition, an engineering project can be a subsystem in a larger system (or a work package or work unit) for which some individual is held responsible. The individual so designated may be called a "project manager," "project engineer," "engineering manager," "engineering team manager," "engineer in charge," "work package manager," "subdivision work manager," "engineering task force manager," or other such titles. These titles signify that some individual is held responsible for, and has the authority to manage, the engineering activity in the literal sense of the word. This definition also means that any undertaking to perform some specified engineering work on a specified budget and schedule is a project—unless the undertaking is a subset of a project: a work package, a work unit, or even a job number. Even the subsets of a project will have one individual as a focal point to do the undertaking or to see that the undertaking is carried out on time, within budget, and satisfying the objective of the undertaking.

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3.6

Life cycle of a construction project. (Adapted from Robert K. Duke, H. Frederick Wohlsen, and Douglas R. Mitchell, "Project Management at Fluor Utah, Inc.," *Project Management Quarterly*, vol. 8, no. 3, September 1977, p. 37.)

An engineering undertaking—a project—can come from a customer or from another part of the organization, or it can originate within an engineering department as an unsolicited proposal for a customer. These engineering projects vary in size, from a few thousand dollars upwards to multimillion-dollar projects. Some future engineering projects are astronomical in size: Consider some of the large engineering projects of the proposed natural pipeline to be constructed from northern Alaska to the continental United States. Engineering projects can range from very large to very small.

What is considered as a small engineering project depends on the viewpoint of the engineering department and the organization.

039

One senior engineering manager in a diversified engineering company in the waste water treatment field defined small engineering projects as those which met most of the following criteria:

Total duration is approximately 3 to 12 months.

Value is between \$5000 and \$100,000.

The project team is in daily or at most weekly communication on a personal basis.

Only a few (two to four) cost centers work on the project and they are closely related.

Manual methods of recordkeeping are more effective than automated systems.

The project manager has quick and direct access to those people who have the detail on schedule, cost, and technical content data.

The work-breakdown structure has no more than four tiers.

There are no formal assistant project managers or subproject managers.

In practice, the real differences between small projects and large projects are the amount of detail required for large projects, the more rigorous documentation required, and the large number of work packages. The larger the project, the more complex everything becomes. The principles, concepts, and management processes remain the same.

PLANNING AND THE LIFE CYCLE

Now that we have defined an engineering project, and have concluded that the project has to be managed, what implications does the system life cycle have for such projects? The answer to this question is to be found in one of the first management activities in the life cycle by the project manager, namely, planning the engineering project.

No matter how small a project may be, it needs a plan—a document that lays out a strategy that clearly defines *what* is to be done, *why*, *by whom*, *when*, and for *how much*. A plan is needed even if a project is a subset in a larger project.

An engineering project plan is a document that outlines a strategy on how future events in the project will be handled. A plan, which deals with future events, is by its very nature cast in the context of starting something today and finishing it at some time in the future—a life cycle.

The essential elements of an engineering project plan are the following:

A summary of the essentials of the project written in such a manner that anyone can get a grasp of the project. It states briefly what is to be done and how it is to be done, and lists the end-product or service deliverables.

A work-breakdown structure that has enough detail to identify the relationships of work packages, work units, and job numbers.

A citation of tangible milestones that can be counted, measured, and evaluated in such a way that there can be no ambiguity as to whether or not a milestone has been achieved. There should be a correspondence of milestones to project budgets to facilitate adequate monitoring.

An event logic network (an activity network) that shows the sequencing of the elements (work packages, work units, and job numbers) of the project and how they are to be related—which can be done in parallel, series, etc.

Separate budgets and schedules for the project elements and the individual that is to be held responsible for these elements.

An organization interface plan that shows how the project relates with the rest of the world—customer, line-staff organizations, subcontractors, suppliers, and other clientele that have some role in the project.

A plan for how the project is to be reviewed—who reviews the project, when, and for what purpose.

A list of key project personnel and their assignments in the project.

The project plan for a small engineering project need not be elaborate. The project plan that we have outlined above is meant to be only representative. The level of detail and the content of the plan can be expanded as needed from the above "plan for the project plan."

PROJECT CHANGES

Even though a project has been well planned, there will probably be some changes in the project as it is completed. In this section some of the changes affecting a typical project are depicted.

The project changes in its nature during the life cycle. Expenditures, people, level of effort, and organizational involvement all

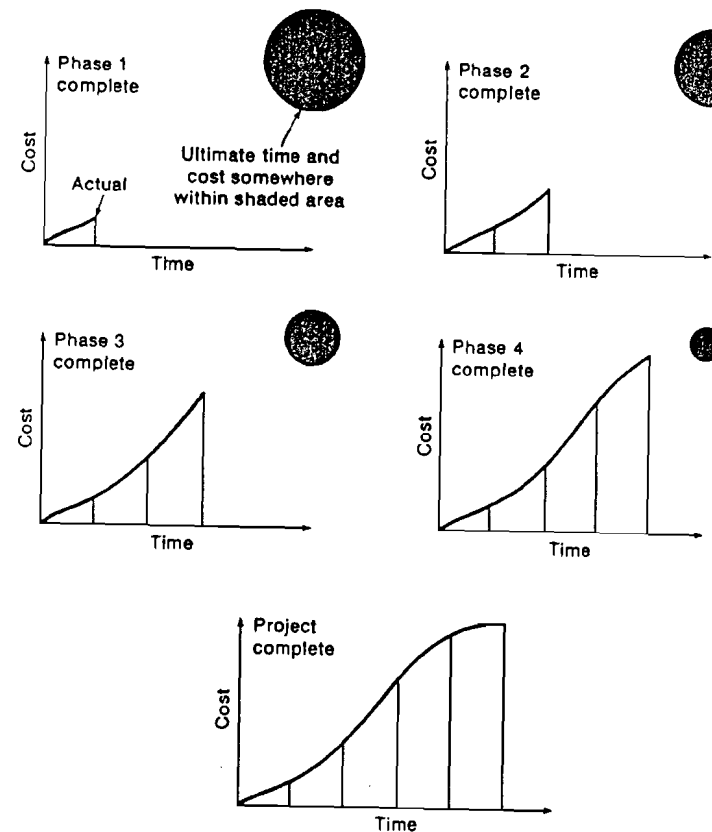
change as the project goes from idea generation through to its operational phase. The uncertainty related to time and cost of completion diminishes as the project nears its completion. Archibald has portrayed this diminishing uncertainty of time and cost in the manner shown in Fig. 3.7. Archibald notes:

The specified result and the time and cost to achieve it are inseparable. The uncertainty related to each factor is reduced with completion of each succeeding life-cycle phase. Figure [3.7] illustrates the reduction of uncertainty in the ultimate time and cost for a project at the end of each phase. In phase 1, the uncertainty is illustrated by the largest circle. The area of uncertainty is reduced with each succeeding phase until the actual point of completion is reached.¹⁴

When a decision is made to develop the project, the management function of *organizing* comes into play. The human and nonhuman resources requirements are identified and obtained in the quality and quantity needed to support the project. The human resources used on a system during its life cycle will vary. Different personnel skills are required as the project is initiated, grows, and declines. A single individual may be all that is assigned when the project is in the conceptual stage. After the project is approved for further funding, a team of engineers is assigned to a skeleton organization to begin definition of the project objectives and hardware-software tasks and subtasks. A conceptual framework for the project is finalized; schedules and costs are detailed. Then additional personnel are assigned to carry out the development and design work. Design engineering is completed and actual construction of the product is begun. The project organization continues to exist, but it exists in more of a surveillance mode. A production organization takes over the operation of the project; this organization attains peak strength. The product is delivered to the customers along with field engineering services, installation and checkout, and field support services. Finally, field modification, if required, is carried out. At this time the life cycle of the project has ended; personnel still remaining on the project are returned to their permanent organization, perhaps to be placed on a new project in the organization.

Litton Industries, in their Litton Microwave Cooking Division, provides an example of the role that the organizing function plays in the management of a project. In the engineering department of this division, a functional form of organizational structure has been changed to a task-team structure. For each approved engineering project, a task team is assigned. The task team is composed of a

¹⁴Russell D. Archibald, *Managing High-Technology Programs and Projects*, Wiley, New York, 1976, p. 23



3.7
Relative uncertainty of ultimate time and cost by life-cycle phase. (From Russell D. Archibald, *Managing High-Technology Programs and Projects*, Wiley, New York, 1976, p. 23.)

design engineer, a stylist, technicians, draftspeople, quality and manufacturing engineers, a marketing manager, buyers, and a home economist. As the team progresses through its development cycle, additional people are assigned, such as industrial engineers, cost accountants, quality control personnel, and production managers. An engineering project manager is assigned to manage this interdisciplinary project from the initiation of the development cycle until a steady level of production is reached.¹⁵

When human resources enter the picture, the *motivating* function of management comes into play. Managers need to become

¹⁵See William W. George, "Task Teams for Rapid Growth," *Harvard Business Review*, March-April 1977, for further description of how engineering task teams are used at Litton Industries, Inc.

82 concerned about the satisfaction of both the organizational and people needs of the project. The motivation function has application throughout the project's life.

Directing—that management function which is concerned with the decision process—is integral to the development and design of the project. Whether or not to continue development of the project is a key decision that has to be considered at various points in the life cycle of the project. Finally, the *controlling* of the project, i.e., using organizational resources as planned to successfully accomplish project objectives, comes into play. When a manager goes to meetings held for the purpose of reviewing the progress of a project, he may be required to perform the following activities:

Reschedule the organizational resources being applied to the project.

Approve a change in the technical specifications.

Require that revised cost estimates be established for the development phase of the project.

Approve a change in personnel working on the project.

Recommend to higher-level management whether or not the project should be continued.

Of course, an engineering manager carries out these managerial functions—planning, organizing, motivating, directing, and controlling—in a somewhat continuous fashion throughout the life cycle of the project.

CONFLICT MANAGEMENT AND PROJECT LIFE CYCLE

An important part of the management of a project is dealing with the people who are working on the project, particularly as those people conflict with each other as they work on a project.

The ability to effectively manage conflict is usually given as one of the characteristics of effective project management. Conflicts of one sort or another invariably arise during the life cycle of a project. Several research studies have reported on the nature of conflict in project management. Thamhain and Wilemon have studied conflict management from the perspective of the individual project life-cycle stages.¹⁶ Their study presents the conflict issues associated with the four accepted stages of projects: project formation, buildup, main program phase, and phase-out. Their study also presents some recommendations for reducing the consequences of conflicts.

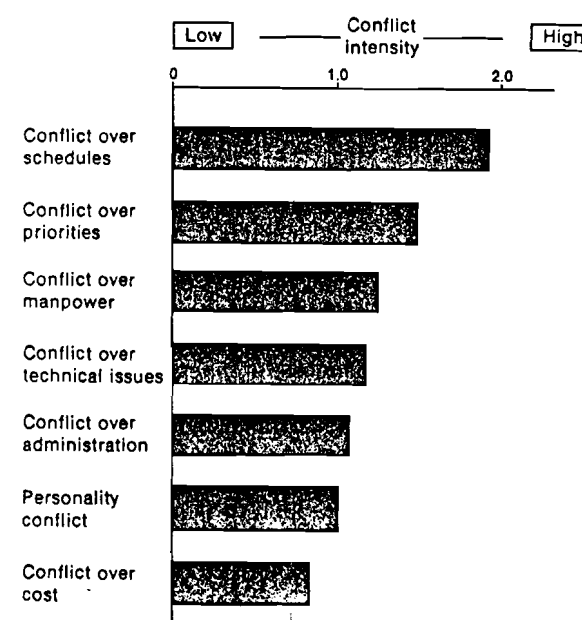
¹⁶Hans J. Thamhain and David L. Wilemon, "Conflict Management in Project Life Cycles," *Sloan Management Review*, vol. 16, no. 3, Spring 1975.

Thamhain and Wilemon sampled project managers from a variety of technology-oriented companies. Project managers were asked to rank the intensity of conflict experienced for each of seven conflict sources. The seven potential conflict sources were:

- 1 Conflict over project priorities
- 2 Conflict over administrative procedures
- 3 Conflict over technical opinions and performance tradeoffs
- 4 Conflict over manpower resources
- 5 Conflict over cost
- 6 Conflict over schedules
- 7 Personality conflict

Figure 3.8 presents the mean intensity experienced for each

Mean conflict intensity profile over project life cycle. (From Hans J. Thamhain and David L. Wilemon, "Conflict Management in Project Life Cycles," *Sloan Management Review*, Summer 1975.)



3.8

- 84 of the potential conflict sources over the entire life of the projects. Areas most likely to cause problems for the project manager during the entire life cycle are schedules, project priorities, and manpower resources.

Thamhain and Wilemon suggest some measures to minimize many of the potential problems arising out of the conflict found in the life cycle of projects. Table 3.8 summarizes their specific suggestions.

SIGNIFICANCE OF A LIFE-CYCLE APPROACH

On the surface, the concept of the life cycle that has been put forth in this chapter suggests a checklist to be followed in a mechanical fashion. Certainly no checklist has ever been useful for very long in any situation as dynamic as the management of an engineering project. We do not intend that the system and the questions that complement the model in Tables 3.1 through 3.5 be used as a checklist. Rather, we hope that the engineering manager accepts the notion that engineering activities are generally characteristic of the pattern suggested in these models; the complementary questions associated with these models can become a guide for understanding the totality of the engineering job to be done—and the questions to be asked in the doing of that job.

Answers to the questions outlined in the phases of the life cycle help the engineering manager recognize where a project or task is at any given time. The questions themselves suggest where the project should be at a phase in the life cycle. A good way to view these questions is to look backwards and see the phases the project has been through and then try to determine where it is currently located in its life cycle. When its current position is known, the use of foresight comes into play. Looking ahead provides a good perspective of both the present and the past.

Recognizing the existence of a life cycle in projects can have considerable value for the engineering manager and the people who are bringing products or services through an engineering analysis. To approach engineering management on a life-cycle basis can have value in several ways:

1 It encourages a deliberate engineering management philosophy to be followed. It systematically postulates an approach to managing the effort in advance and reduces the damage that so often results from stopgap, crisis-oriented decisions. The very existence of a life-cycle approach enforces a scientific approach to the planning and control that is to be carried out in the management of the activity.

2 It helps to force a specific analysis and review of

Major conflict sources by
project life-cycle stage

MAJOR CONFLICT SOURCE AND RECOMMENDATIONS FOR MINIMIZING DYSFUNCTIONAL CONSEQUENCES			3.8
PROJECT LIFE-CYCLE PHASE	CONFLICT SOURCE	RECOMMENDATIONS	
Project formation	Priorities	Define plan clearly; joint decision making and/or consultation with affected parties Stress importance of project to goals of the organization	
	Procedures	Develop detailed administrative operating procedures to be followed in conduct of project; secure approval from key administrators; develop statement of understanding or charter	
	Schedules	Develop schedule commitments in advance of actual project commencement Forecast other departmental priorities and possible impact on project	
Buildup phase	Priorities	Provide effective feedback to support areas on forecasted project plans and needs via status review sessions	
	Schedules	Carefully schedule work-breakdown packages (project subunits) in cooperation with functional groups	
	Procedures	Contingency planning on key administrative issues	
Main program	Schedules	Continually monitor work in progress; communicate results to affected parties Forecast potential problems and consider alternatives Identify potential "trouble spots" needing closer surveillance	
	Technical	Resolve technical problems early Communication of schedule and budget restraints to technical personnel Emphasize early technical testing Facilitate early agreement on final designs	
	Manpower	Forecast and communicate manpower requirements early Establish manpower requirements and priorities with functional and staff groups	
Phase-out	Schedules	Monitoring schedules throughout cycle Consider reallocation of available manpower to critical project areas prone to schedule slippages Attain prompt resolution of technical issues which may impact schedules	
	Personality and manpower	Develop plans for reallocation of manpower upon project completion Maintain harmonious working relationships with project team and support groups; try to loosen up "high-stress" environment	

ongoing projects or tasks. All too often an engineering project is initiated and left on its own. People assigned to the project become dedicated to making the project work; often this dedication becomes so strong that the completion of the project becomes more important than an ongoing evaluation of the work to see whether or not the project should be completed.

3 Answering the questions in the phases of the life cycle is a demanding task. Seldom can one individual answer these questions. A team approach is required, bringing the team together at a regular basis to find the answers—or, perhaps just as important, to recognize that answers to the questions are not yet available.

4 It forces a wider view of the systems nature of the project. An example can be drawn from recent industrial experience to illustrate this point.

During the late 1960s and the 1970s several large United States corporations entered the residential construction business. One such corporation built a plant in the Southeast for the construction of modular houses. This corporation brought its high-technology manufacturing know-how to the operation of this plant. Key innovations drawn from production-line technology were introduced into the fabrication of modular homes. The factory became a good example of production technology. The production engineer who was the original project manager for the design, development, and construction of the plant did a superb job of bringing everything together. The plant was completed on time and within budget. The project manager was appointed as the plant manager of this facility. Production of modular houses started and soon rose to the plant's 40-hour weekly rate potential. At about this time some discomforting problems became evident:

The inventory of modular houses filled up the adjoining warehouses and overflowed onto the outdoor space on the company's property.

At the construction sites local building codes were found to be inconsistent with the configuration of some of the modular houses that had been constructed.

The mounting costs of transporting the modular house units to the construction sites indicated that the plant was not constructed in the right location.

The forecasts for modular housing were allowed to dictate the need for land acquisition—a clear failure to synergize the plant production and land acquisition activities.

The organization that was in the residential construction business was staffed with a mix of managers heavily biased toward production management. Consequently an undue amount of time and resources was spent on the improvement of the modular housing production activity; too little time was spent on the home real estate development and construction business and how that business related to the fabrication of modular housing units.

The reader will probably immediately note that some of these problems were not of an engineering nature and therefore out of the jurisdiction of the engineering manager. However, the systems idea that "everything is related to everything else" has to be considered. If a systems life-cycle profile model had existed for the design and construction of this plant—which it did not—there is a high probability that many of these larger systems issues would have emerged in sufficient time to do something about them.

The main larger systems issue was the whole residential construction business of this company. The plant was just a subsystem. If more careful analysis had been carried out during the development life cycle of this business activity, substantial monies would have been conserved for the corporation.

SUMMARY

In this chapter we have put forth the philosophy of a system life-cycle approach to engineering management and the value of such a philosophy for those people who manage engineering activities. An engineering manager is a person who accomplishes engineering goals through other people. An effective engineering manager influences the course of future events in his organization.

To see the larger whole in any management undertaking is a mind-stretching task—a task left to the manager who facilitates the perception of the larger whole through the use of a model similar to the systems life-cycle concept.

The philosophy of a life cycle in human events is found in many different segments of our society. An approach that uses a philosophy of a life cycle makes good sense. That is why we believe this philosophy should be embraced.

DISCUSSION QUESTIONS

1 What is meant by the statement "Each system has natural phases of development"?

- 88
- 2 Identify and briefly define a model of the phases of the life cycle of an engineering project.
 - 3 The conceptual phase may be the most important phase in a system life cycle. Defend or refute this statement.
 - 4 What are some of the key characteristics of the definition phase?
 - 5 In the production phase of the life cycle, the inadequacies of the analysis conducted in the preceding phases will come to light. Why is this so?
 - 6 What are some of the categories of cost escalation?
 - 7 What conclusions can be reached about a system's economic and technological feasibility if it is in its operational phase?
 - 8 In which phase does a system's sales life cycle begin?
 - 9 An engineering project that is a failure can have some value for the organization. Why?
 - 10 What are some of the management implications of the life-cycle concept?
 - 11 What are the essential elements of an engineering project plan?
 - 12 What are some of the potential conflict sources in the management of a project?

QUESTIONS FOR THE ENGINEERING MANAGER

- 1 Does the idea of the system life cycle have any particular application in this organization?
- 2 What are the engineering methods that are currently in use in this organization for evaluating the progress of an engineering project in its life cycle?
- 3 Have there been any cost overruns in engineering projects in this organization? What actions have I taken to reduce the probability of future overruns?
- 4 Are there opportunities in this organization to which the system life-cycle concept could be applied?
- 5 What are the essential elements of an engineering project plan as currently defined in this organization? Do the assigned engineers understand these elements?
- 6 Do I understand the changes that occur in an engineering project during its life cycle? What degree of control do I have over these changes?
- 7 How do I manage the assignment of personnel to a project according to the needs of the project's life cycle?
- 8 Is there any opportunity for a task-team structure to be used in this organization?
- 9 Have there been any conflicts in the management of engineering projects in this organization?

- 10 What methods exist for the resolution of conflicts within this organization? How successful have these methods been?
- 11 How effectively are decisions being made in this organization? What input do the assigned engineers play in the strategic technological decisions of this engineering community?
- 12 What techniques are currently in use for determining where the assigned projects are in their life cycles? How effective are these techniques?

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THE 4 HUMAN SUBSYSTEM IN ENGINEERING

This chapter presents an overview of the human subsystem in engineering management. The subsystem will be described from the viewpoint of the many roles the engineering manager is required to play as he carries out his managerial responsibilities. One of these roles, that of *motivator*, is particularly significant to the engineering manager, since the effectiveness of motivation in the organization can influence a mission's success or failure. In this chapter we will give particular attention to the manager's role as a motivator.

The reader should gain an appreciation of the "interdisciplinary generalizations" about the human subsystem in modern engineering organizations. Human subsystem involves just about everything associated with the human element. Taken in its extreme meaning, all management matters would fall into the area of the human subsystem, since management means working with other people to accomplish organizational purposes. An understanding of the human subsystem requires some knowledge of sociology, psychology, anthropology, communications theory, semantics, cybernetics, decision theory, logic, philosophy, leadership, and so on! How can the manager hope to develop expertise in all these disciplines in order to be able to manage effectively the human subsystem of an organization? It would be difficult to become an expert in so many disciplines, but the manager can gain an understanding of what these disciplines have to contribute to the management of people. Good management results when managers use their experience, their intuition, and interdisciplinary generalizations to guide them in their relations with other people.

¹Term credited to F. J. Roethlisberger in *The Elusive Phenomena*, Harvard Graduate School of Business Administration, Boston, 1977.

This approach may sound quite unscientific to the engineer. It is, however, the essence of what it takes to succeed in dealing with people: an understanding of the interdisciplinary generalizations about people in their workplace. The application of interdisciplinary generalizations in dealing with people can be approached in a rational manner. Indeed, the development of management thought and theory has been accomplished from such a rational base.

THE RATIONAL NATURE OF MANAGEMENT

Most books on management encourage the manager to develop a systematic approach to the work of management. Such books examine and analyze the managerial functions of planning, organizing, motivation, direction, and control in a systematic, rational fashion. There is much to be said for treating the manager's job in this manner. Much of what the manager does can be learned and is reducible to logical, rational thought processes.

Engineering managers would readily agree there is a need to develop rational thought processes in applying the management functions. But they would also readily admit that many of their challenges cannot always be met by simply applying rational thought. Some of the problems (and opportunities) that come to the manager's attention for resolution may seem to defy any logical solution—particularly where the human subsystem is involved.

These human-subsystem problems are difficult to analyze in a logical manner because the manager himself is a key factor in the situation. Most of what an engineering manager does is to interact with people, both inside and outside the organization. He interacts with a group of "clientele"—a body of people who have a vested interest in the problem (or opportunity) at hand. These clientele are the principal sources of the information the manager needs to make decisions; they are also the group through which the problem has to be worked and the solution implemented. Consequently, the manager's skills in interacting with these clientele are a key factor in how successful he will be in achieving organizational objectives.

It is not enough for the manager to be simply logical and rational in his practice of the management functions. He must also find ways to put himself into the picture of the human subsystem of the organization. To do this requires an ability to "humanize" the managerial role. When the managerial role is so performed, there is a good chance that the rest of the organization will reflect this performance.

The failure to allow for the human element in management was dramatically exemplified by problems at the General Motors Corporation Vega Plant at Lordstown, Ohio. Many of the production line stoppages and other problems at this plant were attributed to a lack of empathy for the production workers and the assembly-line envi-

ronment in which they worked. Hoping to avoid a similar human conflict, the plant manager of a new Volkswagen plant in New Stanton, Pennsylvania, set up an "unusual training program for assembly line foremen as the . . . plant gears up for production of its Rabbit model next year The German-based auto builder's approach to worker-management relations was kicked off last week with a three-day seminar for new supervisors on the 'value of the person' in the workplace."²

Comparing the experiences of these two situations should help the engineering manager decide what to do about developing his own skills in humanizing his managerial role. Engineering schools are making a contribution, with more schools developing curricula around the theme of "humanizing the engineer."³

There is a large body of literature in the behavioral science field devoted to managerial techniques for improving interpersonal relations. This body of literature has an important place in the lexicon of engineering management. It focuses on the engineering manager's ability to work with people—to improve his perceptions of the technologists with whom he works to accomplish organizational ends.

The nature of the interpersonal relationships between the engineering manager and the individuals and groups with whom he works is not so much a matter of organizational structure as it is a matter of *style of interaction*. The manager plays many roles in these interactions. His perceptions of the roles, and the flexibility with which he plays them, are important factors in his success. One must remember that these roles cannot be separated from the rational thought process of managing—planning, organizing, and controlling the activities in the organization. These thought processes are carried out within the context of interpersonal interactions through which the manager accomplishes results by working with other people. As one examines the variety of these interactions, their impact on the nature of the engineering manager's many roles should be clarified.

ROLE PLAYING IN ENGINEERING MANAGEMENT

In this section we examine the roles that an engineering manager plays and how these roles impact on his work as a manager.

A TECHNOLOGIST

To supervise technical people, the manager has to have an understanding of the technology involved. Imberman found that engineers

¹"It's Strictly Carrot, Not Stick, at Rabbit Plant," *The Pittsburgh Press*, Mar. 5, 1978.

²See "Engineers Train for the New World of Business," *Business Week*, Jan. 16, 1978.

resent supervision by nonengineers. They want managers they can respect for their knowledge, ideas, and expertise.⁴

An engineering organization exists to develop a technology and to facilitate its effective use in some market context. An engineer who becomes the manager of technology will find himself in a conflict situation: *technologist versus manager*. A manager, particularly one in a rapidly changing technical world, faces the difficult challenge of keeping a balance between appraising progress in a technology and facilitating the work of people whose main objective is to maintain a level of the state of the art in that technology.

The engineering manager provides a focus for technical leadership—establishing technical objectives and providing for the application of technical knowledge in the organization. Therefore, he plays a dual role. As a technologist, or a technical strategist, he defines the technical targets, sets the system boundaries, determines the priorities, and develops the guidelines for the measurement of the output. As a critic, he passes judgment on the adequacy of the work of the other technologists.

Engineers recognize that their work must be evaluated. They know that someone—or some group—has to pass judgment on the technical relevance of what they are doing. We often assume that this judgment is done by the peer group. However, someone must organize the peer group to be able to pass judgment on the technical work; it is the manager's job to use the peer group as a vehicle to evaluate the effectiveness with which technical objectives are being attained. Even in this context, the manager's role as a technologist requires that he know enough about the technology involved to be able to ask the right questions—and know if he is getting the right answers.

The role of the technologist-manager as a critic may be illustrated by an example from the academic community. In an engineering school, promotions are based primarily on the judgment of peers. In principle, such judgment is collective and objective, and it is related to the contributions the faculty member makes to the university. These contributions are usually valued highly in the decision as to a faculty member's qualifications for promotion. For example, a key criterion for promotion to the academic grade of full professor is the national-international image the candidate has attained in his field. Evaluations of faculty and of technologists outside the university are sought. Many peer groups are involved in reviewing the fitness of a faculty member. The dean of the engineering school, who has some understanding of the technology involved, serves mainly as a facilitator to organize a process whereby the peer group has an opportunity to function as a group critic. The initiation of new academic programs, the modification of curricula, and the de-

⁴W. Imberman, "What Bugs Engineers?" *Machine Design*, Aug. 24, 1978, pp. 88-92.

velopment of strategies for research are some additional areas where the dean of the school serves as facilitator of peer-group actions.

This example from the academic community illustrates the manager-technologist's responsibility to see that a mechanism exists for eliciting technical leadership from the technologists in the organization to help appraise results. If the engineering manager can organize the technical talent in the organization to evaluate progress, he need not worry about trying to keep up with every new technical development in his field. When he needs a technical evaluation of a problem (or opportunity), he can organize a temporary team of technical experts to advise him. If the manager does this as a matter of course in the organization, it will tend to strengthen the peer group as an evaluation mechanism. Peer groups will take on this role as a part of their ongoing activities. When this happens, the manager can concentrate on the nontechnical aspects of his managerial role.

In effect this peer group evaluation is carried out at Texas Instruments through the manner in which this company manages innovation. A key part of this process is accomplished through the "idea concept" whereby an individual can submit a proposal for funding of a development project. The approval of such a project includes an evaluation by a peer group. After the development project is funded, a team is organized to provide the disciplines required to accomplish the project. The use of such a team at Texas Instruments has helped to foster a cultural ambience where "it's impossible to bury a mistake in this company; the grass roots of the corporation are visible from the top. There's no place to hide in TI—the people work in teams, and that results in a lot of peer pressure and peer recognition."⁵

AN AGENT

A second role that the engineering manager plays is that of an agent—one who represents and acts for another in a transaction. As an agent, the engineering manager "markets" the capabilities and outputs of the technical people to his clientele—customers, higher levels of management, outside clients, and other groups that have a need for the products or services of the organization. Since many of the top-level decisions affect the technical people in the organization, someone has to represent their interests in these decisions. Management meetings provide ample opportunity for the engineering manager to act as an agent of the technical workforce and to negotiate for the best interests of the engineers and scientists. This suggests another role for the manager—the role of negotiator.

⁵"Texas Instruments Shows U.S. Business How to Survive in the 1980s," *Business Week*, September 18, 1978, p. 81. Reprinted by special permission. (c) 1978 by McGraw-Hill, Inc. All rights reserved.

96 A NEGOTIATOR

A negotiator is one who arranges an agreement on an issue. Engineers can see the need for someone who is a competent negotiator for the technical organization and can effectively resolve the conflicts among the various clientele of that organization.

There is inherent conflict in an organization because of the way we divided up the work to be done. Engineering departments usually have many experts with special knowledge that can be used to solve specific technical problems. These experts see the technical world through their specialty. This causes them to develop a form of parochialism that tends to restrict their view of the world: they see only their part of the world and nothing else. An engineering manager has to negotiate the conflict that arises out of this parochialism so that the best overall decision is made for the organization. This negotiation role is also manifested in the engineering manager's responsibilities in serving as a member of a team for labor negotiation and strategies, contract negotiations, and working out the conditions of employment for new employees.

The manager must exercise negotiation skills to protect the interests of his people. Many situations in engineering management involve a give-and-take bargaining, where the engineers expect their manager to look out for their best interests and negotiate the best deal possible for resources to support the organization. Many times the skills of negotiation center around the engineering manager's role as a logistician.

A LOGISTICIAN

A logistician is one who procures, distributes, maintains, and replaces human and nonhuman resources for the organization. The term "logistics" has a military connotation, describing the discipline of providing the supplies to support the fighting forces in their field operations. An engineering manager serves as a logistician for his organization and supplies the resources so that the technologists can do their work. In this role, the technologists expect the manager to be tough, shrewd, and an expert in the political process of organizational in-fighting. Engineers are aware of the resource constraints imposed by the organization's budget. They see the budget-allocation process as a time when many managers in the firm compete for scarce resources. A manager who succeeds in obtaining a good budget for his organization will be viewed as a success by the engineers working for him; they will have the equipment, space, and materials needed to carry out their work. Conversely, if the manager is not successful in competing for these scarce resources through the budgeting process, he may be viewed as a failure irrespective of his technical and managerial skills.

In either case, with an adequate or inadequate budget, the

manager will have to carry out the role of logistician for his people. If the manager is a skillful logistician, this strength can compensate for deficiency in other roles. Engineers can excuse the other inadequacies if their manager obtains the resources they need to carry out their work and to achieve success as individuals as well as contribute to organizational goals.

As a logistician, the manager does a lot of things that no one else wants to do. Perhaps these pedestrian but necessary duties are not properly called logistics duties—some of them may be considered as supply clerk duties. Sometimes they are viewed as trifling and irritating. They involve answering correspondence, smoothing relations with clientele, maintaining social contact with sister organizations, participating in protocol meetings, unsnarling administrative foul-ups, etc. All this busy work has to be done by someone; engineers resent getting involved in such work and typically view it as unproductive or downtime activity, to be avoided at all times. They are grateful to have the manager take care of all this paper shuffling and leave them free to do their technical work.

In the role of organizational logistician, the engineering manager is involved in many activities that have little to do with the technical work being carried out. But if the logistics work is not carried out to the satisfaction of the engineers, the technical work will suffer. Most of this work is short-range in nature, taking care of resource needs for the immediate future. However, there are long-term or strategic logistic needs as well. This suggests the next role of the engineering manager: a strategist for the organization.

A STRATEGIST

A strategist is one skilled in the use of science and art in the development of a sense of future direction for an organization. As a technical strategist the engineering manager is concerned with the selection of engineering objectives and goals and the design of a plan for utilization of organizational resources most economically to accomplish objectives and goals. The senior engineering manager of an organization is expected to work as a member of the top level management team in the design of overall organizational purposes. He represents the engineering community in this respect and is expected to contribute engineering know-how in a synergistic fashion along with marketing, production, and finance strategies to attain the organizational purposes. In the capacity of a technical strategist, the engineering manager is dealing with diverse, fundamental problems, issues, and opportunities. He manages an intellectual process of collaborating with other key people in affirming the basic purpose of the organization. The external engineering world has to be put into perspective, the organization's resources analyzed, the competition assessed, questions concerning societal and environmental con-

98 tributions answered, and finally the purpose for the organization as a whole determined. All this work is carried out so that the engineering effort is consistent with higher organizational objectives. If this role is done well, the manager can face the hardships and uncertainty of the future with confidence and organizational self-reliance. This will be recognized by members of the organization; an attitude of well-being and personal satisfaction will result. Professional people who are given career counseling will often want to know what future the organization has—and how they can fit into that future. These career counseling sessions introduce another key role of the engineering manager, viz., that of *counselor*.

A COUNSELOR

A counselor is a person who participates in an exchange of opinions and ideas and gives advice and guidance. There are many situations in which an engineering manager is called on to serve as a counselor to individuals and to groups of clientele. This counsel covers a wide spectrum ranging from advising top management on program development strategy to the job-performance counseling given to a professional.

A skillful manager will use nondirective counseling to help his professionals make their decisions. In this type of counseling, the manager does not attempt to give advice directly. Instead, he asks probing questions about the decision under study, thus leaving the initiative to the individual. Nondirective counseling is an art. It requires the patience to listen without passing judgment; the individual is led through a series of questions to realize for himself what the manager may already know. When a decision is made, the professional feels that it was his decision, and not one made by the manager.

The authors have worked with the director of a large R&D laboratory who is known internationally for his technical knowledge. This director is more of a technologist than a manager. His skills in the management functions—planning, organization, etc.—are below average; yet his laboratory is successful. Some of the reasons for this success hinge on this individual's skills in counseling his project managers on their research through a nondirective approach in a group situation. When key decisions have to be made—for example, to commit resources to a research project—this director will start a line of questions like: "Have you thought of this?" "What would happen if you did thus and so?" "What are the five or six things you believe to be the most important considerations in this research project?" These kinds of questions and many others are put to the project managers quietly and diplomatically. If there are inadequate answers, the director proceeds to question more intensely in these areas; he never seems to react to an answer except to ask

another question. If the research project has not been thoroughly analyzed, this lack of analysis soon comes out. Finally, the project manager says something like: "I would like to study this situation some more and get back in touch with you." The counselor-director responds: "That would be very useful!"

Within his laboratory, this director has an image of a very decisive person, yet his decisions are always worked through his managers along the lines we described. He is much admired and emulated by his people. His ability to do nondirective counseling is by far his most important managerial strength. He provides technical leadership by drawing on the talents of his senior technical people and thus multiplies the total technical leadership available to the organization.

Even though the engineering manager serves in the capacity of a nondirective counselor, he must not forget his role as a disciplinarian in the organization.

A DISCIPLINARIAN

A disciplinarian is one who enforces organizational policies and procedures and keeps the organization on the most promising path toward objectives. This is a role that draws on the manager's teaching and taskmaster skills. It is also a role where the manager has to make tough decisions about an individual's potential growth in the scheme of things. A disciplinarian's role is not an easy one—and it is a role that managers like to forget, for some of the decisions that have to be made are unpopular. Fairness, equity, and objectivity are all considerations that are important to keep in mind as the manager carries out the role of a disciplinarian.

In carrying out this role, the manager puts a lot of emphasis on the control function of management, i.e., seeing that things are happening according to the established plan. If a study of actual organizational progress shows a departure from the progress that was planned, then corrective action has to be instituted. It is important that this corrective action be instituted quickly so that organizational wasted effort is reduced and so that the professionals perceive the ambience of the organization as motivational in nature.

A MOTIVATOR

In the capacity of a motivator, the engineering manager is responsible for providing an environment in which people attain social, psychological, and economic satisfaction in their work. Engineers are used to dealing with problems and opportunities that are typically well-defined; the forces bearing on these problems and opportunities can be counted, measured, and evaluated. When the engineer comes into contact with the managerial aspects of his job, there is a tendency to look for those forces that can be measured. Many of the

100 forces of management, particularly the motivation of people, may at times be so nebulous as to deny any real definition and evaluation.

An important aspect of the behavior of people centers around the motivation patterns that are found in the human subsystem. An engineering manager must work through and for others as he performs his managerial role. Consequently, he requires an understanding of the forces that motivate the individual in the workplace.

To motivate people is to stimulate them to action. People are motivated by a wide variety of stimuli. Sociologists, psychologists, psychiatrists, and behavioral scientists are some of the professionals who have studied the theory and practice of motivation. It would be impossible to summarize in one chapter all their findings about the factors and forces that motivate people. About all we can do is make some observations about the factors that seem to have an influence in motivating an individual to action—to do something in support of organizational objectives.

To motivate an engineer, the manager should try to understand what engineers look for and aspire to in their work. Raudsepp comments on this as follows:

First, engineers want to feel that their work is interesting; they want a feeling of personal professional growth.... Secondly, an engineer wants a salary at least equal that of other engineers on his level.... Third, engineers want status that is more than symbolic; they do not value grandiose titles and regard them as placating devices to deflect their attention from more concrete symbols of status and higher salaries. Fourth, they want effective communication with other components of the organization; they want to feel that top management knows what they are doing; they want to be kept informed about company policies, plans, and operations outside their own work areas. Fifth, engineers want effective managers who can become involved in the engineers' projects.... Sixth, engineers want modern, up-to-date facilities and ample working space.⁶

As one might expect, engineers are motivated by factors directly related to their job situation.

JOB MOTIVATIONAL FACTORS

Over many years of dealing with engineering organizations in a workshop situation, the authors have conducted a survey using the questionnaire shown in Table 4.1. This questionnaire is given to profes-

⁶Paraphrased from E. Raudsepp, "Motivating the Engineer. The Direct Approach Is Best," *Machine Design*, Nov. 24, 1977, pp. 78-80.

Please indicate the five items from the list which you believe are the most important in motivating you to do your best work.

4.1

- _____ 1 Steady employment
- _____ 2 Respect for me as a person
- _____ 3 Adequate rest periods or coffee breaks
- _____ 4 Good pay
- _____ 5 Good physical working conditions
- _____ 6 Chance to turn out quality work
- _____ 7 Getting along well with others on the job
- _____ 8 Having a local house organ, employee paper, bulletin
- _____ 9 Chance for promotion
- _____ 10 Opportunity to do interesting work
- _____ 11 Pensions and other security benefits
- _____ 12 Having employee services such as office, recreational, and social activities
- _____ 13 Not having to work too hard
- _____ 14 Knowing what is going on in the organization
- _____ 15 Feeling my job is important
- _____ 16 Having an employee council
- _____ 17 Having a written description of the duties in my job
- _____ 18 Being told by my boss when I do a good job
- _____ 19 Getting a performance rating, so I know how I stand
- _____ 20 Attending staff meetings
- _____ 21 Agreement with agency's objectives
- _____ 22 Large amount of freedom on the job
- _____ 23 Opportunity for self-development and improvement
- _____ 24 Chance to work not under direct or close supervision
- _____ 25 Having an efficient supervisor
- _____ 26 Fair vacation arrangements
- _____ 27 Unique contributions
- _____ 28 Recognition of peers
- _____ 29 Personal satisfaction

Source: Adapted from David I. Cleland and William R. King, *Management: A Systems Approach*, McGraw-Hill, New York, 1972, p. 370.

sionals in engineering organizations—engineers, scientists, and engineering-scientific managers—as a way of getting them to think about the conditions of motivation in their organization. After the respondents fill out these questionnaires, distribution of the responses is then tabulated for the participants as a group and posted for all to see—to use as a focus for a discussion on the subject "What motivates people to do their best work?" A lively discussion then follows, as the participants are given a good idea of what motivates them and their peer group. A pattern of responses has emerged from these people, indicating the items listed in alphabetical order in Table 4.2 as being the most important in motivating them to do their best work.

From these results, one might make the following observation: Good pay is an important factor in motivation—but so are many other factors. It is important to note that many of these factors deal with the workers' environment and the interpersonal relationships

Job motivational factors—
most frequent response

- 4.2**
- Chance for promotion
 - Chance to turn out quality work
 - Feeling my job is important
 - Getting along well with others on the job
 - Good pay
 - Large amount of freedom on the job
 - Opportunity for self-development and improvement
 - Opportunity to do interesting work
 - Personal satisfaction
 - Recognition of peers
 - Respect for me as a person

between the engineering manager and the peer group. It is also obvious that the manager has a significant impact on how well the members of his organization are motivated to do their best work.

When an engineering manager studies Table 4.2, he might ask himself the question: "Given that these are the factors that motivate an individual to do his best work, what have I done to create an environment in the organization to highlight these factors?" If the manager wants to go further, he can administer this questionnaire to his people to get an insight into how they feel about the organizational climate for motivation. In administering the questionnaire to his engineers, the manager should be careful to do the following:

- Get everybody together.
- Explain the purpose of the questionnaire.
- Have the people fill out the questionnaire.
- Preserve the anonymity of their responses.
- Immediately tabulate the results.
- Discuss the results with the participants.
- Be prepared to be "put on the spot."
- Take action about the suggestions that are bound to come out of the discussion.
- Provide the people with feedback on what is being done.

If the manager is willing to do this, he should gain benefits for his organization by way of a better climate for motivating people. However, the manager must be careful, because if the use of this questionnaire is not handled properly, it could create a negative impression. For example, if the manager administers the questionnaire,

shares the results with his people, and then does nothing about their suggestions, the climate for motivation could be impaired.

There are many different factors that motivate people to do their best work. A project engineer may be motivated more by having a "large amount of freedom on the job" than by "adequate rest period or coffee breaks," since he can probably take a coffee break anytime it is convenient for him to do so. By contrast, a worker who fills a key position on a production line may feel that having an "adequate rest period or coffee break" is more important to him as a motivator. This suggests that individuals are unique in themselves and how they view their place of work and what motivates them. Individuals are conditioned by many factors in their lifetime, including their cultural background, education, and previous experience, to name a few. These factors play a role in the way an individual perceives his environment and how he is motivated. Juclius⁷ has identified several intangible factors that an individual brings to his job that influence his behavior. These intangible factors include:

- Psychological attitudes
- Physiological condition
- Political beliefs
- Moral standards
- Professional standards
- Prejudices and habits

The above factors are very difficult to measure; an understanding of their existence can give insight into how they may influence an individual's on-the-job behavior. A manager should be aware of their effect on the individual's job performance and should try to understand why an individual acts as he does. A person's attitude about his job and the effectiveness with which he performs his duties may be influenced by early experiences, apart from the current job situation. Each of us is a victim of everything that has gone before us in our lifetime. All these previous experiences and attitudes combine with our current job situation to make our motivation and behavior complex and not necessarily rational.

UNDERSTANDING HUMAN BEHAVIOR

Which of the roles described above are the most important for the manager? Of course, this depends on the situation at hand; the manager "plays many parts." His perceptions of these many parts and of the time to play each part are important factors in his success. These

⁷Michael J. Juclius, *Personnel Management*, Irwin, Homewood, Ill., 1963, p. 86

104 roles do not exist independently of each other or of the rational thought processes of the manager. Managers vary in their ability to play these roles; strength in one role can help assure success for a manager. Managers who are interested in a personal development program for themselves should strive to improve their capabilities in all roles.

The real impact these roles have on the manager is the realization that all of them have a strong person-to-person characteristic. As the manager plays the many parts, his interpersonal skills determine how well he is able to represent the engineering community in these various roles.

There are no peopleless organizations. This statement may seem redundant and trite, yet as one observes the behavior of some engineering managers trying to manage technical people, one is struck by their insensitivity to the human subsystem in the organization. Why is this so? For many reasons, no doubt. We believe that a large part of this problem stems from a lack of exposure for the engineering manager to the subject of the behavior of people.

An important generalization about the behavior of people deals with their needs and how these needs affect their motivation. Maslow,^{*} an early writer in the field of motivation, gave us a good insight into the subject of needs and motivation.

A CONCEPT OF MOTIVATION

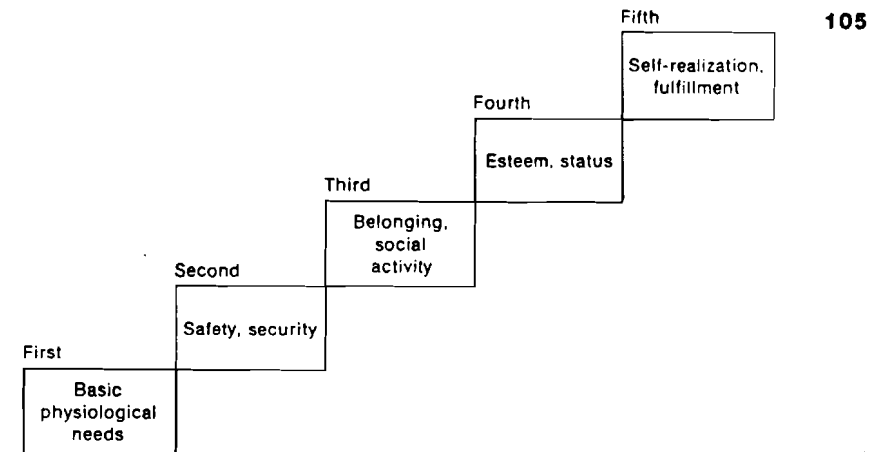
Maslow put forth the idea of a "hierarchy of human needs" that placed the various needs of individuals in relationship with one another. This hierarchy of needs was developed to describe certain levels of human needs that motivate individuals in general. Maslow's concept is best portrayed in Fig. 4.1.

The relationships of the needs illustrate the idea that certain basic physiological requirements (thirst, hunger, sex, sleep, etc.) have to be satisfied before an individual can be expected to seek satisfaction of higher-level needs. As higher-level needs are satisfied, the individual shifts his drive for satisfaction to another category. Put another way: A satisfied need is no longer a motivator of action.

Modern management theory has accepted Maslow's hierarchy-of-needs concept as a reasonably good description of reality. The higher-level needs in this hierarchy have to do with the mind and the spirit rather than the body. One management author considers these higher-level needs "nebulous in nature." According to Davis:

Dissatisfied workers usually attribute their dissatisfaction to something more tangible, such as wages. Many wage dis-

^{*}A. H. Maslow, "A Theory of Human Motivation," *Psychological Review*, vol. 50, 1943, pp. 370-396, and *Motivation and Personality*, Harper, New York, 1954.



Order of priority of human needs. (Adapted from Keith Davis, *Human Relations at Work*, 3d ed., New York, 1967.)

putes are consequently not really wage disputes, and meeting the wage request does not remove the basic dissatisfaction which existed . . . [Such] needs have the following characteristics:

- 1 They are strongly conditioned by experience.
- 2 They vary in type and intensity among people.
- 3 They change within any individual.
- 4 They work in groups, rather than alone.
- 5 They are often hidden from conscious recognition.
- 6 They are nebulous feelings instead of tangible physical needs.
- 7 They influence behavior. It is said that we are logical only to the extent our feelings let us be.⁹

Experienced managers will attest to the real-world implications of human needs and motivation in their organizations. For such managers the use of participatory techniques to help satisfy the professional's needs and to bring about a higher degree of motivation on the part of the professional is essential.

⁹Keith Davis, *Human Relations at Work*, 3d ed., McGraw-Hill, New York, 1967, p. 333

PARTICIPATION IN MANAGEMENT

Participation is defined by Keith Davis as "an individual's mental and emotional involvement in a group situation that encourages him to contribute to group goals and to share responsibility for them."¹⁰

Three important ideas are inherent in this definition: first, an ego involvement is necessary on the part of the individual; second, participation stimulates the individual to make a contribution to the organization; and third, participation encourages people to accept responsibility for an activity.¹¹ Participation can help the people in an organization develop a sense of belonging. It can raise productivity, improve morale, and provide an outlet for the creativity and innovation skills of people.

The desire of people to participate in their organization's activities is "rooted deep in the culture of free men around the world, and . . . is probably a basic drive in men."¹² Comparative studies in England and the United States suggest that participation is a basic human drive rather than a cultural acquisition.¹³ The Japanese approach to decision making puts emphasis on getting the participation of the people who are to be affected by the decision. The use of project teams, task forces, and similar approaches to specific organizational problems is an effective way of getting people to participate.

Litton Industries, Inc., has used task teams operating within a functional structure to achieve and manage a very rapid growth. These task teams foster a high degree of team participation, which is considered to be more important than individual contribution. The results speak for themselves in the Microwave Division: "The division's sales grew from \$13 million to \$130 million in five years, its profit increases have averaged 75% per annum, it enjoys market leadership in every product category, with market shares ranging from 25% to 75%, and its unit production has increased from 125 units per day to more than 3,000 per day."¹⁴

Participation is not all "roses." There are practical limits to what it can do for the manager. If people do get involved, they will expect to be kept informed on what is happening in the organization, particularly on those matters in which they have participated. Thus the manager will have to be careful to keep the communication channels in the organization open to provide relevant feedback.

When project teams are used in the management of an engineering project, a high degree of participation of the professional

¹⁰Ibid.

¹¹Ibid.

¹²Ibid.

¹³See N. R. F. Maier and L. R. Hoffman, "Group Decision in England and United States," *Personnel Psychology*, vol. 15, Spring 1962, p. 86.

¹⁴Reprinted by permission of the Harvard Business Review. Excerpt from "Task Teams for Rapid Growth," by William W. George (March-April 1977). Copyright © 1977 by the President and Fellows of Harvard College; all rights reserved.

people occurs. In such a situation, most important decisions require the participation of all team members. Unilateral decision making rarely happens. If the manager is used to a clear line of authority to make unilateral decisions, the participation of team members in the decision process can be frustrating. The result, however, is worth the effort, as George notes: "The strength for this decision-making process is, of course, the high caliber of the decisions themselves and the high degree of individual commitment toward carrying out the decisions in an effective manner. Both are direct results of broad participation in the decision-making process."¹⁵

Participation should be meaningful so that the people see their contribution assisting in the accomplishment of organizational goals and objectives. Engineers participate in the engineering organization's work through providing specialized skills when and where required. Participation is a form of personal involvement over and above the providing of specialized skills when and where needed. Participation means that the individual gets involved in an activity to the extent of sharing the responsibility for seeing that something is accomplished. Authority for making a decision about what is to be done still rests with the responsible manager, who makes that decision after considering the viewpoint of his team members. Participation does not mean that the manager gives up his legal right to make decisions on behalf of the organization; it means that he provides an opportunity for the people in the organization to contribute advice and counsel as to what that decision should be. A couple of examples known to the authors will illustrate this point.

The president of a manufacturing company became interested in instituting project management in the engineering department in his organization. He set up a team of engineers representing the various disciplines assigned to the engineering department. They were asked to select a leader and were given the objective: "Determine if the company should institute project management." The team was provided financial resources to cover its operating expenses, such as travel, clerical help, etc. It studied this problem for several months, interviewed many of the company's engineers and engineering managers, visited other companies that were using project management, and developed a bibliography on project management. Periodic briefings were held for the president and his staff. Over a period of several months, many questions were studied: What can project management do for the company? What problems might project management create? What strategy should be adopted to implement the organizational changes? Finally, recommendations were made as to how the company could reorganize its engineering department along a project-management approach.

¹⁵Ibid., p. 80.

The team continued in existence during the transition to a project-management approach, to act as a sounding board on the organizational change being brought about and to suggest fine tuning of the strategy being implemented. When the change was completed, the team was disbanded.

In another situation, the manager of a manufacturing development laboratory in a large R&D organization needed to invest substantial monies in additional equipment to enter a new market area. A team of engineers was organized to study the organizational needs, determine what was available in new equipment, and make recommendations to the R&D laboratory director on what equipment to procure. The team's recommendations were accepted by the manager and the equipment was subsequently obtained.

Using teams of professionals to participate in making decisions helps to satisfy the needs of the members and the organization. A valuable system of checks and balances comes into play as the members participate in building the data bases necessary to support the decision. By participating, the team members gain insight into the work of management as well as a sense of contributing to organizational objectives.

An important aspect of participative management deals with the manager himself. He, too, is subject to all the forces of human behavior that affect his organization, many of which have been presented in the previous pages. His decisions, which affect the entire organization, are not solely economic, and technical in nature but are conditioned by his prejudices, ethics, politics, attitudes, morals, etc. He may decide issues on ethical or moral bases rather than on the basis of what makes the best engineering sense for the organization. He may make a decision based on what he personally wants to do rather than what is the most logical to support the organizational goals. Christensen, Andrews, and Bower have given us some insight into such a situation:

We must acknowledge at this point that there is no way to divorce the decision determining the most sensible economic strategy for a company from the personal values of those who make the choice. Executives in charge of company destinies do not look exclusively at what a company might do and can do. In apparent disregard of the second of these considerations, they sometimes seem heavily influenced by what they personally want to do.¹⁶

This is not a complimentary thing to say about managers—but they are human, too, and are only as rational and logical as their feelings permit them to be!

¹⁶C. Roland Christensen, Kenneth R. Andrews, and Joseph L. Bower, *Business Policy: Text and Cases*, 4th ed., Irwin, Homewood, Ill., p. 448. © 1978 by Richard D. Irwin, Inc.

Another facet of human behavior that can facilitate or negate the management of an organization is the attitude held by managers about people in general. In the next section, we explore the role that attitudes play in the management of people.

ATTITUDES TOWARD PEOPLE

An attitude is a state of mind or feeling with regard to some matter. The attitude that a manager has about the nature and behavior of people will be reflected in how successful he is in leading people toward the organizational goals. In 1960, Douglas McGregor challenged some of the traditional attitudes about managing people in his book, *The Human Side of Enterprise*.¹⁷ In this book, McGregor put forth the idea of "theory X" and "theory Y" as representative of the general attitudes held by managers about the role of people in organizational life. According to McGregor, behind every managerial decision or action are assumptions about human nature and human behavior. For theory X these assumptions are:

- 1 The average human being has an inherent dislike of work and will avoid it if he can.
- 2 Because of this human characteristic of dislike of work, most people must be coerced, controlled, directed, threatened with punishment to get them to put forth adequate effort toward the achievement of organizational objectives.
- 3 The average human being prefers to be directed, wishes to avoid responsibility, has relatively little ambition, wants security above all.¹⁸

Theory Y assumptions about human behavior are in dramatic contrast to these:

- 1 The expenditure of physical and mental effort in work is as natural as play or rest. The average human being does not inherently dislike work. Depending upon controllable conditions, work may be a source of satisfaction (and will be voluntarily performed) or a source of punishment (and will be avoided if possible).
- 2 External control and the threat of punishment are not the only means for bringing about effort toward organizational objectives. Man will exercise self-discretion and self-control in the service of objectives to which he is committed.

¹⁷Douglas McGregor, *The Human Side of Enterprise*, McGraw-Hill, New York, 1960.

¹⁸*Ibid.*, pp. 33-34.

3 Commitment to objectives is a function of the rewards associated with their achievement. The most significant of such rewards, e.g., the satisfaction of ego and self-actualization needs, can be direct products of effort directed toward organizational objectives.

4 The average human being learns, under proper conditions, not only to accept but to seek responsibility. Avoidance of responsibility, lack of ambition, and emphasis on security are generally consequences of experiences, not inherent human characteristics.

5 The capacity to exercise a relatively high degree of imagination, ingenuity, and creativity in the solution of organizational problems is widely, not narrowly, distributed in the population.

6 Under the conditions of modern industrial life, the intellectual potentialities of the average human being are only partially utilized.¹⁹

McGregor's viewpoint points out the inadequacies of an approach to dealing with people that limits the cooperation (and the participation) in the organization. The theory Y approach to management strongly implies that the manager's attitude toward the people in the organization limits or encourages those people to contribute to an organizational goal. If a manager is perceived as believing that "people are no good" and have to be managed on a theory X basis, the people will respond accordingly. Conversely, if he is perceived as being sensitive to the needs of people and as recognizing that their work can be a source of satisfaction to them, that they usually like to accept responsibility, and that they are willing to participate in the affairs of the organization, they will respond with enthusiasm and creativity. One might note then that the state of human relations in the organization is in great part dependent on the quality of leadership that the manager provides.

LEADERSHIP

Leadership is the capacity to be a leader—the ability to lead. A leader is one who leads others along a way.

Leadership is so interwoven with the human element of organizations that it is difficult, if not impossible, to distinguish where leadership and human behavior stop and start. Leadership is a responsibility of all managers. A leader's role is to get things done through other people; he can do this only by influencing the behavior

of the people who have a responsibility to do something for the organization.

Leadership in the political, business, military, church, and other environments has been written about extensively in literature. To consider all the viewpoints about leadership is far beyond the scope of this book. We will examine very briefly some of the approaches that have been used to investigate leadership. The engineering manager can then consider his own philosophy about his role as a leader as he does further reading in the field of leadership.

Prior to the 1930s, leadership was viewed as something that an individual possessed—certain traits and characteristics of successful leaders. Early scholars in the field identified such traits as integrity, decisiveness, intelligence, energy, teaching skills, etc. Many lists of these traits were developed in research studies in the field. For the most part, these traits were believed to be inherited rather than acquired. The list of traits that successful leaders had grew and grew. Finally, over 100 of these traits or characteristics were identified. One of the basic difficulties in using the trait approach is that "seldom, if ever, do any two lists agree on the essential traits and characteristics of effective leadership."²⁰

More recent views of leadership have taken a new direction, looking not only to the individual's traits but to the behavior of the leader and those people who are being led. McGregor²¹ summarizes some of the generalizations from recent research on leadership, which portray "leadership as a relationship." According to McGregor:

There are at least four major variables now known to be involved in leadership: (1) the characteristics of the leader; (2) the attitudes, needs, and other personal characteristics of the followers; (3) characteristics of the organization, such as its purpose, its structure, the nature of the tasks to be performed; and (4) the social, economic, and political milieu. The personal characteristics required for effective performance as a leader vary, depending on the other factors.²²

McGregor's viewpoint is important because "it means that leadership is not a property of the individual, but a complex relationship among these variables."²³

Other approaches have explained leadership as a type of behavior: e.g., (1) dictatorial, (2) autocratic, (3) democratic, and (4) laissez-faire. The operating styles of these types of leaders consist of

¹⁹S. G. Huneryager and I. L. Heckmann, *Human Relations in Management*, 2d ed., South-Western, Cincinnati, 1967, p. 243.

²¹McGregor, op. cit., pp. 179–189.

²²Ibid., p. 182.

²³Ibid.

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getting work done through fear (the dictator), centralizing decision making in the leader (the autocrat), decentralizing decision making (democratic leadership), and allowing the group to establish its own goals and make its own decisions (*laissez-faire* leadership).

Still other approaches deal with leadership as being specific to the particular situation in which it occurs. Therefore, a leader has to take cognizance of the groups of people (superiors, subordinates, peers, etc.) to which he is related as well as the organizational structure, resources, goals, time variables, etc. This suggests the real complexities of trying to understand what leadership is all about. A basic conclusion can be drawn: A successful leader must be adaptive and flexible—always aware of the needs and motivations of those whom he tries to lead toward fulfillment of organizational goals. He must be aware of how he performs as a leader and how his behavior affects the performance of those on whom he depends. As a leader tries to change the behavior of his people, a change in his behavior may also be needed.

Research into the matter of leadership continues, since we really know little of what it is and why it works sometimes and fails at other times. The engineering manager who strives to improve his leadership abilities is encouraged to do reading in the area. The references at the end of the chapter can be helpful in this respect.

SUMMARY

The engineer who is a purist might say that the approach we have suggested in this chapter is unscientific. We might agree. But can people be managed scientifically? Are people always rational? Is the management of people more a science than an art? Questions like these have been debated by management theorists and practitioners for a long time. Let's take the easy way out and say that the management of people includes elements of both science and art. It is the artful aspect that we were primarily concerned with in this chapter.

We described the many roles that a manager plays as he maintains a multiplicity of interfaces with his clientele. His success in accurately and effectively maintaining these roles is reflected in the degree to which the organization—and the people—accomplish respective objectives.

If one treats the management of people as primarily an artful activity, then one can make observations rather than establish scientific fact. One can study the behavior of people in a particular situation and make general observations about the nature of their behavior. Change the environment a little and their behavior may change slightly or significantly. This does not alter the importance of observ-

ing behavior and drawing observations from that behavior. These observations can be integrated into the manager's strategy and *modus operandi* for managing people.

The viewpoint put forth in this chapter is a practical view of some of the factors that motivate professional personnel. Motivation is related to the needs of people; the engineering manager must understand the nature of these needs if he is to deal successfully with the challenge of motivating professional people.

We ended the chapter on the subject of leadership. In the next chapter, we will examine an important role of the leader—that of an effective communicator to his clientele.

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DISCUSSION QUESTIONS

- 1 What is meant by the phrase "interdisciplinary generalizations"?
- 2 In what manner might the work of management be described as rational in nature?
- 3 How might the human subsystem of an organization be defined?
- 4 What is meant by "humanizing" the engineer?
- 5 The authors take the position that the engineering manager plays many roles in discharging his responsibilities. What is meant by this statement?
- 6 Identify and describe the typical roles of an engineer as defined in this chapter. Should any additional roles be added?
- 7 If an engineering manager is not strong in an aspect of technology in his organization, what should he do to overcome this weakness?
- 8 What is the most important role that an engineering manager plays? Defend your choice.
- 9 What is meant by "nondirective counseling"? When should such counseling be used by the manager?
- 10 What do engineers look for in their work?
- 11 What are some of the key motivational factors affecting job performance in an engineering community?
- 12 Distinguish between a theory X and theory Y engineering manager.

KEY QUESTIONS FOR THE ENGINEERING MANAGER

- 1 Have I ever designed a "conceptual model" of the human subsystem in this organization?

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- 2 What professional reading have I done which gives me some background in the interdisciplinary nature of engineering management?
 - 3 What action have I taken to humanize my engineering manager's role? How do the engineers assigned to this organization perceive my role in this respect?
 - 4 What do I perceive as my many parts in managing this organization?
 - 5 Have I organized peer groups in this engineering organization to help me evaluate the adequacy of technology being provided?
 - 6 Can technological mistakes be buried in this organization? What can I do to prevent this sort of thing from happening?
 - 7 How successful has my counseling been in this organization? Do the professionals in the organization feel comfortable in coming to me with their problems—and suggestions?
 - 8 What factors motivate the engineers in this organization? Would it be possible to determine what key factors motivate these engineers?
 - 9 Does Maslow's concept of hierarchy of needs give me any insight into the behavior of people in this organization?
 - 10 What means have I provided to encourage participation in this engineering community? Has there been meaningful participation? Why or why not?
 - 11 Are all the decisions made in this organization made on a rational basis? Why or why not?
 - 12 Do the engineers perceive me as a theory X or theory Y manager? What influence does my leadership style have on this perception?

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COMMUNICATION 5 IN ENGINEERING MANAGEMENT

A few years ago alumni of Purdue University were asked what had been most conspicuously lacking in their education. These alumni, predominantly engineers, declared overwhelmingly: "Communication."¹

An engineer may be judged more by the way he is able to express his ideas than by his degree of technical knowledge. Everyone with whom the engineer comes in contact is able—or at least thinks he is able—to judge the way the engineer is able to speak and write.

The possession of technical knowledge is the reason engineers are hired; when they are hired there is an assumption that they can communicate this knowledge in their place of work with their work associates—superiors, subordinates, and peers. An engineer does not generally have a good image as a communicator—one who conveys information about some matter. He may be effective in communicating with fellow engineers, but when he comes in contact with other people with whom he must work, communication can become a problem. For example, an engineer who is a member of a project team may work with people from other disciplines, such as marketing, finance, accounting, information systems, or production. If he is not able to communicate what needs to be said about engineering to these people, misunderstanding can occur.

Early in his career an engineer is chiefly concerned with communications of a technical nature. Later on in the engineer's career, nontechnical, management communications become more important. Typically, engineers come to a decision point between 3 and 7 years after graduation. At that point, they choose either to stay in their engineering specialty or to move into engineering management. The communications needs of the two paths are different. Those remaining in engineering specialties write technical reports and

¹Cited in Robert Haakenson, "Improving Oral Communication," *Effective Communications for Engineers*. McGraw-Hill, New York, 1974, p. 48.

- 338** Luce, R. D., and H. Raiffa: *Games and Decisions*, Wiley, New York, 1958.
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PROJECT 11 SELECTION, CONTROL AND EVALUATION

Engineering projects are building blocks of an organization's strategy to achieve overall objectives. Some engineering projects are successful in achieving those objectives; some never come to fruition, perhaps having proved technically infeasible, too costly to develop, or not adaptable to market demand. This chapter deals with the selection of new projects, the scheduling and control of ongoing projects, and the evaluation of completed projects. Both technologists and those who have responsibility for the management of projects should find the chapter useful. The methods used for project evaluations range from informal discussions to highly structured approaches and models. In this chapter, we discuss the methods that follow a systematic procedure and utilize both subjective and objective data for the evaluation. The methods are presented in sufficient detail so that engineers and engineering managers can use them in their current and future projects.

The engineering manager is responsible for evaluating his projects at all stages of the project life cycle.¹ More specifically, he conducts three types of evaluation:

- 1 Preproject evaluation for the *selection* of the best project from among the prospective projects
- 2 Ongoing evaluation for the *control* of a project in progress
- 3 Postproject evaluation for the *assessment* of the success and efficacy of a completed project

¹See Chap. 3 for a discussion of the project life-cycle concept.

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In preproject evaluation, the projects are compared with respect to relevant criteria defined for project selection purposes. There is a plethora of approaches that managers may choose to use in selecting projects. A few years ago, Karger and Murdick² surveyed several major industrial firms to determine their methods for identifying and developing new products. The responding companies indicated that they used three major dimensions in their evaluations: technical evaluation, market evaluation, and economic evaluation.

Technical evaluation assesses the technical feasibility of developing the project within the time limits established by the company. *Marketing evaluation* addresses the question of whether the project output is compatible with the company's product lines and market strategy. *Economic evaluation*, which is usually subsequent to the first two evaluations, examines the project from the perspective of the company's overall strategic objectives and examines whether investments to support the project are justified by the expected returns.

After the decision is made for the selection of a project, the engineering manager becomes responsible for the implementation of that decision. He works with a team of professionals to complete the project within the time, cost, and technical requirements. In the course of the project, information feedback is generated for the evaluation of the project performance. This process in an ongoing project has been called a *normative evaluation*.³ Project budgets, schedules, technical parameters and control networks are used for such a purpose.

As the project winds down, a different kind of evaluation is necessary to assess how the work has progressed and what has been achieved by the project. This postproject assessment is called *summative evaluation* by Scriven.⁴ It serves two purposes. First, it measures the efficacy of a completed project. Second, the lessons learned in the postproject evaluation provide good insights for the management of future projects.

PREPROJECT EVALUATION

One of the key decisions for an engineering manager is the selection of projects to undertake. The freedom that he has in this decision is usually conditioned by the strategic plans of the organization. Because of the diversity of markets—often geographically dispersed—and the extent of competitive technology in products, the

²D. W. Karger and R. G. Murdick, *New Product Venture Management*, Gordon and Breach, New York, 1972.

³C. H. Weiss, *Evaluation Research*, Prentice-Hall, Englewood Cliffs, N.J., 1972.

⁴M. Scriven, "The Methodology of Evaluation," in *Perspectives of Curriculum Evaluation*, R. W. Tyler, R. M. Gagne, and M. Scriven (eds.), AERA Monograph Series on Curriculum Evaluation, no. 1, Rand McNally, Chicago, 1967, pp. 39-83.

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engineering manager is constrained to a technological strategy endorsed by the organization's senior management. For example, the huge \$14 billion Phillips company based in Holland does not launch a new development unless it is suitable for most, if not all, of its major markets. To survive, the development projects that are undertaken by the company must have high quality, be suitable for production, and be supportable by field engineering.

Within the framework of corporate strategy, the engineering manager needs a rational methodology for the selection of engineering projects. He is responsible for acquainting his professionals with the various methods available for project selection and encouraging the rigorous use of such methods. Members of a project team can be used efficiently as a "decision body" for this purpose. Such a group effort facilitates a dialog in the team that helps to answer such questions as: What project should be selected for funding? Why has a particular project been selected? How does the project fit into the strategic purpose of the organization?

In the ensuing discussion, we will speak of the project selection decision maker as if he were the engineering manager. Of course, the ultimate decision does rest with this manager, assuming such decision is compatible with the strategic direction desired by the chief executive of the organization.

A wide variety of project selection methods has been developed for engineering projects, R&D projects, marketing strategies, and large-scale programs. A summary will be given here to familiarize the reader with the methods that are available.

We can classify the methods in order of increased sophistication as follows:

Rank-ordering methods:

- Simple rank ordering
- Q-sorting
- Weighted ordering
- Successive comparisons

Scoring models:

- Simple scoring model
- Probabilistic scoring model

Utility models

- Simple utility model
- Probabilistic utility model

Hierarchical models

RANK-ORDERING METHODS

Rank-ordering methods are used for listing projects according to their overall desirability. The engineering manager and his profes-

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SIMPLE RANK ORDERING In this method, a square matrix is developed, with rows and columns corresponding to the projects under consideration. The engineering manager compares the project in a column with the projects in the rows one at a time. If he prefers the project in column j to the project in row i , he places a plus sign in cell ij . When the matrix is completed, the number of pluses in the columns are counted. If the comparisons are consistent, the pluses in a column equal the minuses in the corresponding row and their sum determines the ranking of the projects.

For example, if there are n projects, $P_1, P_2, \dots, P_n$, the decision maker starts comparing P_1 in the first column with the other projects. If P_1 is preferred to P_2 , he places a plus in cell (2, 1). If he prefers P_3 to P_1 , he assigns a minus to cell (3, 1), etc. After comparing P_1 with all the other projects and putting the pluses and minuses into the cells of the first column, he continues with the second column and compares P_2 with all the other projects. Of course, if he is consistent, he will now say that P_2 is not preferred to P_1 , because he had decided P_1 was better than P_2 in the first comparisons. Thus, he puts a minus in cell (1, 2).

When the comparisons are completed, the number of pluses in the columns will vary between zero and $n - 1$. The number of pluses under a project indicates the number of other projects to which that particular project is preferred. The project with $n - 1$ pluses will have the highest rank; the others will follow it.

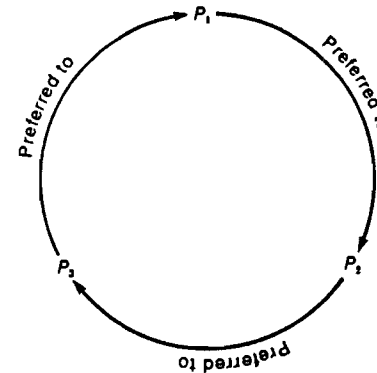
Let us assume that five prospective projects have been compared with each other and the following matrix has been developed:

$P_j \backslash P_i$	P_1	P_2	P_3	P_4	P_5	Number of minuses
P_1	X	-	+	+	-	2
P_2	+	X	+	+	-	1
P_3	-	-	X	-	-	4
P_4	-	-	+	X	-	3
P_5	+	+	+	+	X	0
Number of pluses:						2 1 4 3 0

This matrix shows that consistent comparisons have been made. The number of pluses in each column is the same as the number of minuses in the corresponding row, and they range from zero to 4. The projects are ranked as P_3, P_4, P_1, P_2, P_5 in order of decreasing desirability.

We cannot expect that the comparisons will always be consistent. There can be two types of inconsistencies in comparisons.

- 1 When the decision maker compares P_1 with P_2 , he puts a + in cell (2, 1). Later, when he compares P_2 with P_1 , he again puts a + in cell (1, 2).
- 2 When three or more projects are ranked in such a way that P_1 is preferred to P_2 , P_2 is preferred to P_3 , and P_3 is preferred to P_1 , implying a three-way "circular preference profile" as follows:



This is called "Intransitivity" in decision theory terminology.

When inconsistencies occur, multiple columns have the same number of pluses and they may differ from the number of minuses in the corresponding rows. If this occurs, we have to determine where the inconsistencies are and make new comparisons for the affected projects.

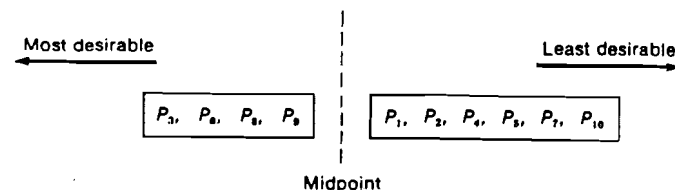
This method has some obvious advantages. First, it is easy to use. Second, it forces the decision maker to make explicit choices in a systematic way. Third, the inconsistencies inherent in the thinking process can be identified by going over the matrix a few times. On the other hand, it has a major disadvantage: the method indicates that a project is more desirable than another one, but it does not provide any information as to how desirable. This disadvantage can be alleviated to some extent by weighting the projects after the ranking is obtained. A weighting scheme is described under the weighted-ordering procedure later in this chapter.

Q-SORTING The Q-sorting method is also used for rank-ordering projects. It uses a very simple procedure, and the results are usually

344 obtained in a shorter time than the simple rank-ordering method described above. The project titles are written on small cards and given to the decision maker. He divides them into two groups, one group containing projects preferable to the other group. He then evaluates the projects in each group and divides them into two more groups, using the same approach. He keeps doing this until all projects are ranked, from the most desirable to the least desirable.

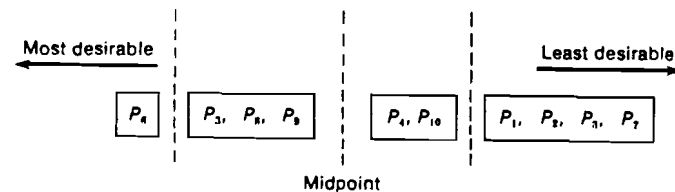
Let us suppose there are ten prospective projects and the engineering manager feels that P_3 , P_6 , P_8 , and P_9 are superior to the rest. He forms two clusters as follows:

Step 1



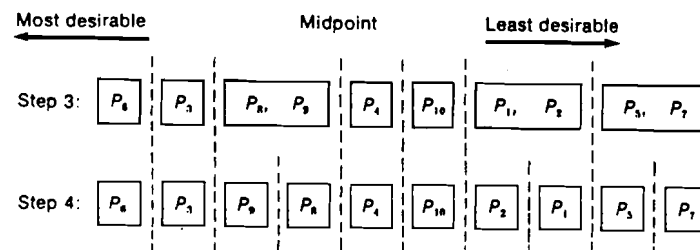
He then divides each group into two subgroups:

Step 2



At this stage, P_6 has already been chosen as the best project, since there is only one item in that cluster.

Continuing with the same process, assume that the subsequent clusters are formed as follows:



After step 4, the manager might wish to compare the two projects ad-

345 jacent to the midpoint. Since the midpoint was established when the complete set of projects was initially divided into two groups, the difference between P_6 and P_4 could be so small that he may want to switch them. If no such change is made, the projects are rank-ordered as grouped in step 4.

Q-sorting has the same advantages and disadvantages as simple rank ordering.

WEIGHTED ORDERING The two methods described above rank the projects in the order of preference. When we see such a list, we know that a project is better than all other projects that are ranked lower than itself. We do not know, however, how much better that project is in comparison with another project. That relative measure can be obtained by applying a weight factor to the projects after their rank ordering is complete. The weights are determined by comparing each project with the next lower-ranked project and dividing a total of 100 points between them to indicate the relative level of preference for each.

Suppose the ten projects rank ordered by Q-sorting in the previous section are to be weighted. Starting with P_6 (the highest ranked project) and P_3 (the next lower ranked project), nine pairs are formed and the total of 100 points is allocated to the two projects in each pair such that if a project is considered to be about twice as good as the next one, they are assigned 67 and 33 points respectively. If one is three times better than the next, then 75 and 25 points are assigned.

Assume the following comparisons are made:

$P_6: 55$ $P_3: 60$ $P_9: 70$ $P_8: 51$ $P_4: 75$
 $P_3: 45$ $P_9: 40$ $P_8: 30$ $P_4: 49$ $P_{10}: 25$

$P_{10}: 60$ $P_2: 65$ $P_1: 55$ $P_5: 52$
 $P_2: 40$ $P_1: 35$ $P_5: 45$ $P_7: 48$

Letting P_7 have a value of 1.0, the other projects are assigned respective values as follows:

$P_6 = \frac{100}{91} = 1.08$
 $P_1 = 1.08 \frac{55}{35} = 1.32$
 $P_2 = 1.32 \frac{65}{35} = 2.46$
 $P_{10} = 2.46 \frac{60}{35} = 3.69$
 $P_4 = 3.69 \frac{75}{49} = 11.07$
 $P_8 = 11.07 \frac{51}{45} = 11.52$

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$$P_2 = 11.52 \frac{1}{10} = 26.87$$

$$P_3 = 26.87 \frac{1}{10} = 40.31$$

$$P_6 = 40.31 \frac{1}{10} = 49.27$$

In this evaluation, the most desirable project, P_6 , is viewed as about fifty times better than the least desirable alternative, P_7 .

SUCCESSIVE COMPARISONS This is another weighting procedure, developed by Churchman, Ackoff, and Arnoff.⁵ It can be used for assigning weights to projects when the combined value of two or more projects is equal to the sum of their individual values as perceived by the decision maker. The method uses the following procedure:

- 1 Rank-order the projects by any method, such as rank ordering or Q-sorting. Let us say that we have obtained the following order:

$$P_1, P_3, P_2, P_4, P_5$$

- 2 Assign a value of 1.0 to the top-ranked project and successively lower values to the others.

$$V_1 = 1.0$$

$$V_3 = 0.8$$

$$V_2 = 0.6$$

$$V_4 = 0.4$$

$$V_5 = 0.2$$

- 3 Make the comparison:

$$P_1 \text{ versus } (P_3 + P_2 + P_4 + P_5)$$

If the combined projects are preferred to P_1 , drop P_3 from the combination and make another comparison until P_1 is preferred to the sum of the others. For example, let us say that the decision maker feels that P_1 is preferred to P_3 and P_2 taken together but considered not as attractive as the combination of P_3 , P_2 , and P_4 . This implies:

$$(V_3 + V_2) < V_1 < (V_3 + V_2 + V_4)$$

$$(0.8 + 0.6) < V_1 < (0.8 + 0.6 + 0.4)$$

$$1.4 < V_1 < 1.8$$

Revise the original value of P_1 by setting it between 1.4 and 1.8. Let us say $V_1 = 1.6$.

⁵C. West Churchman, Russell L. Ackoff, and E. Leonard Arnoff, *Introduction to Operations Research*, Wiley, New York, 1957.

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- 4 Repeat step 3 for the comparison of P_3 versus the combination of all projects ranked lower than P_3 . Suppose P_3 is preferred to $P_2 + P_4$, but there is an indifference between P_3 and $P_2 + P_4 + P_5$. Thus,

$$(V_2 + V_4) < V_3 = (V_2 + V_4 + V_5)$$

$$(0.6 + 0.4) < V_3 = (0.6 + 0.4 + 0.2)$$

$$1.0 < V_3 = 1.2$$

Assign a value of 1.2 to V_3 .

- 5 Repeat the above step for a comparison of P_2 versus $P_4 + P_5$. Suppose we find that

$$V_4 < V_2 < (V_4 + V_5)$$

$$0.4 < V_2 < (0.4 + 0.2)$$

$$0.4 < V_2 < 0.6$$

Let $V_2 = 0.5$ and keep $V_4 = 0.4$ and $V_5 = 0.2$.

- 6 Using the new values, go backwards to check the inequalities developed above. Revise project values as necessary. In other words, start the backward comparisons with the following values:

$$V_1 = 1.6$$

$$V_3 = 1.2$$

$$V_2 = 0.5$$

$$V_4 = 0.4$$

$$V_5 = 0.2$$

For step 5:

$$\text{Check } V_4 \stackrel{?}{<} V_2 \stackrel{?}{<} (V_4 + V_5)$$

$$0.4 < 0.5 < (0.4 + 0.2) \quad \text{OK}$$

For step 4:

$$\text{Check } (V_2 + V_4) \stackrel{?}{<} V_3 \stackrel{?}{<} (V_2 + V_4 + V_5)$$

$$(0.5 + 0.4) < 1.2 < (0.5 + 0.4 + 0.2)$$

$$\text{Let } V_3 = 1.1$$

For step 3 (using the revised value of V_3):

$$(V_3 + V_2) \stackrel{?}{<} V_1 \stackrel{?}{<} (V_3 + V_2 + V_4)$$

$$(1.1 + 0.5) < 1.6 < (1.1 + 0.5 + 0.4)$$

$$\text{Let } V_1 = 1.8$$

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7 Make the forward and backward comparisons as many times as needed. Note that in this example consistent values have already been reached. The final weights assigned to the projects are as follows:

$$V_1 = 1.8$$

$$V_3 = 1.1$$

$$V_2 = 0.5$$

$$V_4 = 0.4$$

$$V_5 = 0.2$$

8 For uniformity of comparisons, normalize these values by dividing each one by the sum of values, i.e.,

$$\text{Normalized } V_i = \frac{V_i}{\sum_{i=1}^n V_i} \quad \text{for } n \text{ projects}$$

In this case,

$$\sum_{i=1}^5 V_i = 4.0$$

Therefore, the normalized values are

$$V_1 = 1.8/4.0 = 0.45$$

$$V_2 = 1.1/4.0 = 0.275$$

$$V_3 = 0.5/4.0 = 0.125$$

$$V_4 = 0.4/4.0 = 0.10$$

$$V_5 = 0.2/4.0 = 0.05$$

$$\text{Total} = 1.00$$

SCORING MODELS

The weighting concept described in the previous models can also be extended to the evaluation of projects under multiple criteria. This is the approach used in scoring models.

SIMPLE SCORING MODEL The preceding methods—simple rank ordering, Q-sorting, weighted ordering, and successive comparisons—require a perception of the *overall attractiveness* of projects. To give a precise definition for overall attractiveness is very difficult. A more realistic method is the evaluation of each project with respect to a number of criteria simultaneously. This is done as follows:

1 Identify relevant criteria. For most project selection situations, five to ten criteria are sufficient.

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2 Define a range for each criterion. The range could be from "very good" to "very bad" for qualitative criteria, and from the highest measurable value to the lowest for quantitative criteria, such as return on investment (ROI).

3 Divide the range of each criterion into intervals. The recommended number of intervals is between five and nine.

4 Rank the criteria in the order of their relative importance and assign weights to them.

5 Assign a numerical value to each interval.

6 Evaluate each project, one at a time, according to the criteria by indicating the interval to which it belongs.

7 Calculate the product of the criterion weights and the criterion intervals. The sum of these products is the project score.

8 Repeat steps 6 and 7 for each project.

9 Rank the projects according to their scores.

The definition of relevant criteria is very critical in scoring models. A dialog among the decision makers and the major clientele groups is often necessary in the first two steps above. The criteria should be clearly defined and easy to evaluate. They should lend themselves to meaningful measurements, either subjectively or objectively. If the scoring model is to be used for evaluating a project proposed by subcontractors, such as the landing gear assembly mentioned in Chap. 10, the relevant criteria could include durability, maintainability, design characteristics, cost, completion time, subcontractor's track record, etc. If we are selecting a project to develop a product in line with corporate objectives, the criteria would include growth potential, profitability, competitive edge, etc.

Use of the simple scoring model is illustrated in Table 11.1. The six criteria listed in the table are all subjective. In addition to these, readily quantifiable criteria can also be included in the list. Depending on the nature of projects under consideration, such relevant criteria may include ROI, projected market share, and net present value.

An important consideration in this model is the precise definition of intervals, representing the levels at which the criteria are satisfied by each project. For example, the "very good" level for the "use of available personnel" may be used for a project that fully utilizes the engineers and draftsmen currently on the company payroll, while a "very poor" level for the same criterion may be assigned to a project that cannot use any of the technical expertise

Simple Scoring Model for a Project

CRITERION	CRITERION WEIGHT (W)	CRITERION INTERVAL VALUES (C)					RATING = W × C
		1.0 VERY GOOD	0.8 GOOD	0.6 MEDIUM	0.4 POOR	0.2 VERY POOR	
Use of available personnel	0.15		X				(0.15)(0.8) = 0.12
Growth potential	0.20			X			(0.20)(0.6) = 0.12
Profitability	0.30		X				(0.30)(0.8) = 0.24
Competitive advantage	0.05				X		(0.05)(0.4) = 0.02
Consistence with technical competence	0.20		X				(0.20)(0.8) = 0.16
Compatibility with existing projects	0.10	X					(0.10)(1.0) = 0.10
Sum:	1.00						Project score: 0.76

available in the company and requires that a project team be formed entirely from outside sources. These levels should be clearly defined for the relevant range of each criterion and should be communicated to the decision makers before the model is developed.

After the project scores are calculated for all projects, the subjective probability for the success of each project is determined. Let us assume that the project shown in Table 11.1 is assigned a 0.85 probability that it will be successful. The expected project score is $(0.85)(0.76) = 0.65$. This is the relative value of a specific project. It is compared with the expected scores of the other prospective projects in order to rank them in the order of their attractiveness.

Notice that, in this example, "profitability" is viewed as being twice as important as the "use of available personnel" and three times as important as "compatibility with existing projects." Also, the relative values of the criterion levels imply that "good" is twice as attractive as "poor" and four times better than the "very poor" category on a scale from 0 to 1.

The results of such a model would indicate that an expected score of 0.56 is better than one of 0.30, but it would not necessarily mean that 0.56 is better than 0.54. When the scores of two projects are so close to each other, we would have good reason to believe that both are superior to one with the score of 0.3, and we would analyze the two candidates more closely. In other words, the scoring model is a good approach to help us introduce a systematic method in judging the intangible characteristics of projects, but it is not a substitute for judgment. Rather, it facilitates the exercise of judgment.

PROBABILISTIC SCORING MODEL The "probability of success" concept used in the simple scoring model incorporates risk into the project selection decision in a very limited sense. It assumes that the project will have a probability p to give us the profile shown in Table 11.1 and a probability of $1 - p$ that all criteria will be at an unacceptable level with a relative value of zero. This concept is extended to a more precise definition of risk in the probabilistic scoring model shown in Table 11.2.

In Table 11.2, the criterion weights and the criterion-level values are the same as those in the previous example. However, the evaluation of the project is done not by merely indicating the level for each criterion, but by assigning probabilities for each level of attainment. The probabilities add to 1.00 for each criterion.

The expected rating for a criterion is calculated by summing the products of interval values and achievement probabilities and multiplying the result by the criterion weight. The calculation for the first criterion is:

$$0.15[(0.3)(1.0) + (0.5)(0.8) + (0.2)(0.6) + (0.0)(0.4) + (0.0)(0.2)] = 0.12$$

After the ratings are calculated for all criteria, the expected project score is determined as the sum of ratings. This score is then compared with the expected scores of the other projects.

Probabilistic Scoring Model for a Project

CRITERION	CRITERION WEIGHT	CRITERION INTERVAL VALUES					EXPECTED RATING
		1.0 VERY GOOD	0.8 GOOD	0.6 MEDIUM	0.4 POOR	0.2 VERY POOR	
Use of available personnel	0.15	0.3	0.5	0.2	—	—	0.12
Growth potential	0.20	0.1	0.1	0.4	0.2	0.2	0.11
Profitability	0.30	0.3	0.4	0.1	0.1	0.1	0.22
Competitive advantage	0.05	—	0.1	0.2	0.5	0.2	0.02
Consistence with technical competence	0.20	0.1	0.6	0.2	0.1	—	0.15
Compatibility with existing projects	0.10	0.5	0.3	0.2	—	—	0.09
Sum:	1.00						Expected project score: 0.71

Relative Values Based on Criterion Distribution

11.3	CRITERION INTERVAL	RELATIVE VALUE
	Below $\mu - 1.75\sigma$	1
	$\mu - 1.75\sigma$ to $\mu - 1.25\sigma$	2
	$\mu - 1.25\sigma$ to $\mu - 0.75\sigma$	3
	$\mu - 0.75\sigma$ to $\mu - 0.25\sigma$	4
	$\mu - 0.25\sigma$ to $\mu + 0.25\sigma$	5
	$\mu + 0.25\sigma$ to $\mu + 0.75\sigma$	6
	$\mu + 0.75\sigma$ to $\mu + 1.25\sigma$	7
	$\mu + 1.25\sigma$ to $\mu + 1.75\sigma$	8
	Above $\mu + 1.75\sigma$	9

The scoring model approach is based on the assignment of subjective values to the various levels of criteria. This assignment is done by dividing the measure of each criterion into several intervals and defining a numerical value for each interval. In our example the criteria were divided into five intervals and the relative values between 0.2 and 1.0 were assigned to them. Other schemes can also be used. For example, Moore and Baker^a recommend that the measure of each criterion be divided into nine equal intervals and a value of 1 be given to the worst and 9 to the best interval. They also recommend that the width of each interval be half of the standard deviation of the distribution of the criterion measure. If the mean of the distribution of the criterion measure (for example, the net present values of prospective projects) is denoted by μ and the standard deviation by σ , the criterion-level values are defined as in Table 11-3.

When the scoring model is used in project selection, it is important to evaluate all projects by the same model in order to assure consistent decisions.

UTILITY MODELS

The critical assumption behind the scoring models is the implication that the relative values of criterion intervals are proportional to the numerical values assigned to them. However, as we discussed in Chap. 10, the values assigned to outcomes by the decision makers are defined by their utility functions and do not necessarily follow a linear relationship with the outcomes. Following this argument, we can extend the scoring models to utility models.

^aJ. R. Moore, and N. R. Baker, "An Analytical Approach to Scoring Model Design: An Application to Research and Development Project Selection," Graduate School of Business, Stanford University, Stanford, Calif.

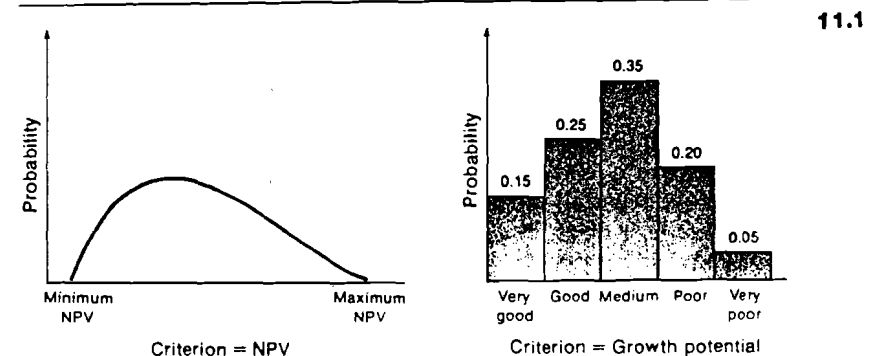
SIMPLE UTILITY MODELS In simple utility models we first develop a utility function for each criterion by assigning 0 utile to the minimum level and 1 utile to the maximum. These functions take various forms, as discussed in Chap. 10. After they are developed, we establish the criterion weights by comparing the relative value of going from the worst to the best level in one criterion versus another criterion. This can be done by using the constant-sum method presented in Chap. 10.

After that, we determine the utility of each project along each criterion and multiply it by the relative weight of that criterion. The sum of these products gives us the utility for the project. If we also multiply it by the probability of success, we obtain the expected utility of the project. This way the projects are ranked not according to the expected scores, but according to their expected utilities.

This approach assumes that the project will fail with a probability of $1 - p$ and the utility of failure will be equal to zero. In reality, a project could have various levels of success. If we determine the probability distribution of a project's outcome for each criterion, we can combine the probabilities and the corresponding utilities to obtain a more realistic expected value for the project's utility. This is the approach taken in probabilistic utility models.

PROBABILISTIC UTILITY MODELS After the criterion weights and utility functions are developed, let us assume that we have also developed subjective probability distributions for the range of outcomes that can be obtained from a project along each criterion. For example, suppose that two of the relevant criteria are the "net present value" and the "growth potential" of the project, and these criteria exhibit the following distributions for a certain project (Fig. 11.1).

Probability distributions for project criteria.



354 Since we are assuming that we have developed the utility functions for these criteria, we can determine the expected utility of the project as follows.

Let E_k = expected utility of project k

W_i = relative weight of criterion i

U_i = utility function for criterion i

V_{uk} = level j of the outcome of project k for criterion i

P_{uk} = probability that the level V_{uk} will be achieved

The expected utility of project k is:

$$E_k = \sum_i W_i \sum_j U_i(V_{uk})(P_{uk})$$

In the above expression, j represents the intervals into which the criteria are divided. For discrete criteria, these are the criterion levels as defined earlier. For example, if the first criterion ($i = 1$) is "growth potential," then the first interval ($j = 1$) is "very good," the second interval is "good," and so on. Hence, V_{123} denotes that project 3 has good growth potential. Going back to the utility function for that criterion, we can easily determine the utility of being in the second interval. This will be the value represented by $U_1(V_{123})$. We then multiply it by the associated probability p_{123} and repeat these calculations for all intervals of all criteria. The probabilities are obtained from distributions similar to Fig. 11.1. Assuming that Fig. 11.1 has been developed for project 3, the value of p_{123} is 0.25. In case of continuous criteria such as the net present value, a large number of intervals can be used for the purpose of numerical integration by the computer. In that case, V_{uk} corresponds to a small interval such as \$150,000 to \$155,000, so that it can still be associated with a finite probability.

So far, our discussion has been limited to the methods of ranking the projects according to their overall attractiveness or evaluating them with respect to a set of predefined criteria. Another approach to project selection is the programmatic approach described in the next section.

HIERARCHICAL MODELS

Projects can be viewed at three major hierarchical levels, as mentioned at the end of Chap. 10:

- 1 Impact level, which deals with issues related to the strategic purpose of the organization
- 2 Target level, which defines the project goals that are to be achieved

3 Operational level, which refers to the projects, strategies, and actions that are under consideration **355**

The decision elements at each of these levels can be developed from organizational policy statements and strategic and operational objectives. At the impact level, we have to ask ourselves what we will ultimately get out of the project effort and determine if the final results will have a positive impact on the strategic objectives of the organization. These objectives are typically established at the corporate level in major corporations, or at the general manager level in smaller organizational units. Some examples of such objectives are listed below:

- Market leadership
- Technical superiority
- Profit maximization
- Social responsibility
- Long-term growth
- Long-term stability
- Broad markets with balanced products
- Strengthening the cash position
- Strategic survival

These are broad, timeless statements that establish the general direction of the organization and become a framework for the decision makers throughout the organization.

At the lower levels of the decision hierarchy, the organizational units establish specific goals in support of the strategic objectives. Typically, these are developed for the departments and divisions in major corporations. The following list includes some examples of such goal statements:

- Improve product reliability by 10 percent
- Develop new technologies
- Improve productivity by 30 percent over the next 4 years
- Penetrate into new markets
- Diversify into new products
- Reduce the air pollution caused by the plant to half of the current level

The goals established for a department or division are such that,

356 when they are achieved, each one contributes to one or more of the organizational strategic objectives. The relative contributions are not necessarily equal to each other. Some goals may have a significant impact on one objective and a negligible impact on another one. By quantifying these contributions, we can develop a relative measure of each goal's contribution to each objective.

The engineering manager operates as a decision maker in a domain constrained by these higher level goals and objectives. He can determine the relative value of each proposed project, but it has very little meaning unless it contributes to the strategic purposes of the organization. Viewed from this perspective, the project selection process becomes a much more important activity than a simple decision at the project level. When the new projects could affect the strategic direction of an organization, it is important that their selection reflect the goals, objectives, strategies, and value structures implied in the decision hierarchy of the organization. The hierarchical model is used for this purpose. It is developed systematically by obtaining relative measures among the levels of the decision hierarchy and also within the elements of each level. The concept is based on the idea that in a decision system, everything is related to everything else. The system interactions and interrelationships are evaluated by using measurable values or by quantifying the decision makers' judgments. When the model is complete, it provides information not only about the relative value of a project but also about the relative impact of each project on each strategy, goal, and objective of the organization.

Referring to Fig. 10.8 and considering five levels similar to those shown in the figure, we find that the basic model takes the following form:

$$V_i = W_m \sum_k \sum_j \sum_l P_{ij} S_{jk} G_{kl} O_{lm}$$

where V_i = relative value of project i

W_m = relative weight of benefit m

P_{ij} = relative contribution of project i to strategy j

S_{jk} = relative contribution of strategy j to goal k

G_{kl} = relative contribution of goal k to objective l

O_{lm} = relative impact of objective l on benefit m

The relative measures used in the model are P_{ij} , S_{jk} , G_{kl} , and O_{lm} . As we combine them for the final result, we obtain numerical values for the arcs and nodes of the network shown in Fig. 10.8. Those values represent the impact relationships among decision elements at all levels of the hierarchy.

An example of the hierarchical model is presented in the Appendix.

ONGOING PROJECT EVALUATION

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During the course of a project's life, it should be reviewed periodically by the engineering manager and members of the project team. For example, one of the authors is a consultant to a product development effort in a high-technology, fast-moving market situation. This project is reviewed every 2 weeks by the project team; the responsible engineering manager is present at these reviews along with the organization's financial, production, and marketing managers. The president of the company attends as many review meetings as his schedule permits. During a recent review meeting it was discovered that a proposed step-up in the technical configuration of the product was incompatible with existing manufacturing know-how. A parallel development in manufacturing technology was immediately initiated to support product technology. Had the review meetings not been held on a regular basis, the information on the lag in production technology might have been missed or delayed; the result could have been a delay in getting the product to market, a delay which would have worked to the advantage of the competition.

Project evaluation through an ongoing review process gives continuous feedback on how the project is progressing. There is no substitute for such a process of getting the project team together to discuss how things are going along the following lines:

What is going wrong?

What is going right?

What problems (and opportunities) appear to be emerging?

How is our competition doing?

Where is the project with respect to schedule, cost, and technical objectives?

Does the project continue to fit into an overall company strategy?

Questions of this nature can serve to motivate discussions within the project team and help to get the status of the project out for all to see.

In addition to the review meetings, a formalized approach to ongoing evaluation also includes the project scheduling and control activities. Project control is an important part of project management responsibility and includes:

Establishment of an anticipated date of completion of the project

Actions and activities necessary to accomplish the goals of the project

A desired or required sequence for performing the activities

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One of the better known and more widely used techniques for project control is the *Gantt chart*. There are also other techniques based on network analyses. We shall look at the Gantt chart, the *critical path method* (CPM), and the *program evaluation and review technique* (PERT).

GANTT CHART¹

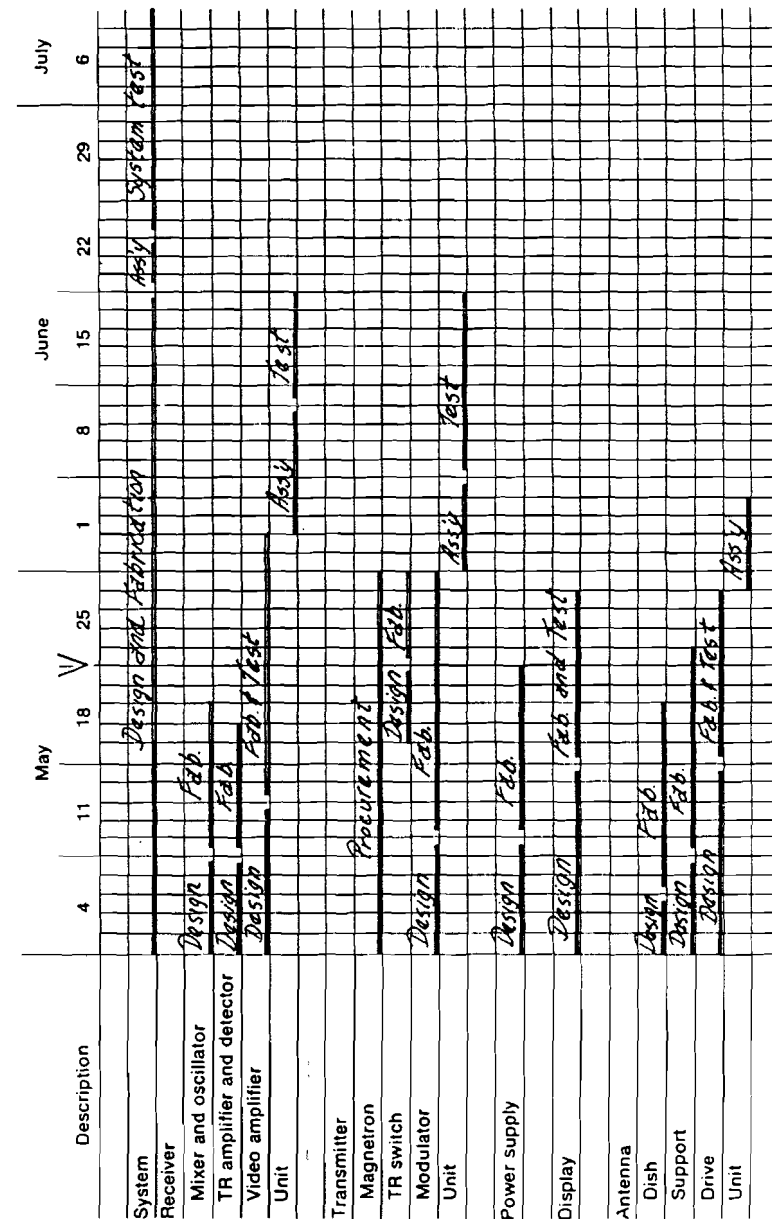
The thrust of the Gantt chart is the graphic portrayal of the progress of a project. In the original charts the governing factor was availability and capacity of personnel and equipment. Extensions of the Gantt chart concept have recognized that the most important factor in scheduling problems is time. These newer charts are called "project planning charts."

Figure 11.2 is an illustration of a project planning chart dealing with the development of an electronic device. The elements of the project are listed on the left-hand side, and units of time in workdays appear at the top. The horizontal bars represent the schedule for the project elements, with specific tasks, activities, or operations written above the schedule line. The time duration of each activity is an estimate provided by people familiar with the activity. Work accomplished is denoted by a solid line in the schedule line. Progress is posted at regular intervals, and the time of each posting is marked by a large V at the top of the chart. A whole range of visual scheduling aids, from self-stick tapes to magnetic scheduling board kits, are now available commercially.

The time the project is behind schedule is usually determined by the maximum delay of any element from the schedule. At the last posting in Fig. 11.2, the project was 6 days behind schedule because of the receiver video amplifier. Some elements, such as the display and antenna units, were ahead of schedule. Other elements were behind schedule, but not as much as the video amplifier. Therefore, bringing the video amplifier up to schedule should have priority and, if the operations and personnel situation permit, the manager should transfer personnel temporarily from display and antenna units—the two farthest ahead of schedule—to the video amplifier.

One disadvantage of the Gantt chart is that it provides no means for assessing the impact of an element's being behind or ahead of schedule. As Cleland and King observe, "simply because a project element is behind schedule does not necessarily mean that the project is behind schedule by that amount. For most projects, only a few dates are critical in the sense that any delay in them will delay the project by a corresponding amount. The impact of slips in

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¹This discussion is adapted from D. I. Cleland and W. R. King, *Systems Analysis and Project Management*, McGraw-Hill, New York, 2d ed., 1975, chap. 15.

360 schedule dates depends upon the interrelationships between elements, which are not easily portrayed.⁸

Networks and network analyses are now being used quite frequently in scheduling management. They address the problem of critical activities alluded to in the above paragraph. We will examine only the two fundamental techniques, CPM and PERT.

CPM AND PERT

PERT and CPM were developed in the late 1950s and currently are being applied widely in contemporary organizations. An integral part of both techniques is the use of networks, called "arrow or precedence diagrams," to depict the precedence relationships of the elements of a project from its inception to its completion.

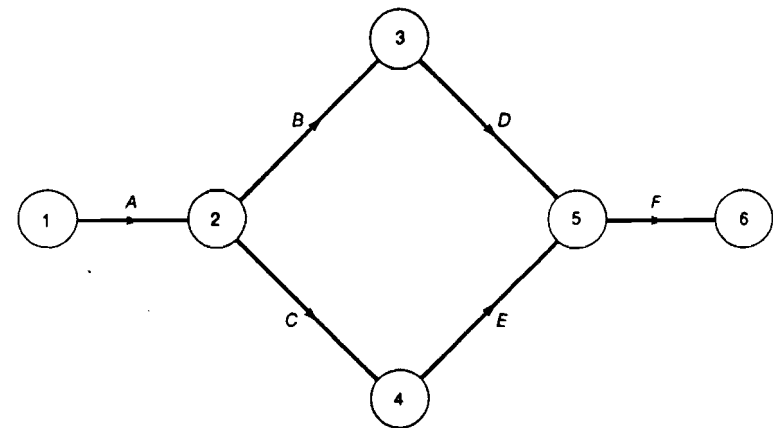
The construction of the precedence diagram requires the decomposition of the project into activities. Then three questions are answered about each activity of the project: What immediately precedes the activity (its *immediate predecessor*)? What can be done concurrently? What immediately follows or succeeds it (its *immediate successor*)? The diagram has two elements: *arrows or arcs* representing the project's activities, and *nodes or events* indicating the intersections of activities. Each activity or arrow has an *initial node* and a *terminal node*. The first initial node is called the *source* and the last terminal node is the *sink*. No activity can start from a node until all activities entering the node have been completed.

Consider a project with six activities, A, B, C, D, E, and F, with the following precedence relationships:

- 1 B and C can be started simultaneously, but each can start only after A is completed.
- 2 D can be started only after B is completed. Similarly C must be completed before E can start.
- 3 F can begin only after both D and E are completed.

Additionally, the time durations have been estimated to be *a, b, c, d, e,* and *f* hours, respectively, for activities A, B, C, D, E, and F. Figure 11.3 illustrates the precedence diagram. Node 2 is the terminal node for activity A, and the initial node for both B and C. Node 1 is the source and node 6 is the sink. Complications sometimes arise in the development of precedence diagrams, but discussion of these is beyond the scope of this book. The reader may consult books on networks mentioned in the Bibliography for a more detailed treatment of the subject.

⁸Cleland and King, op. cit., p. 347.



Example of an arrow or a precedence diagram.

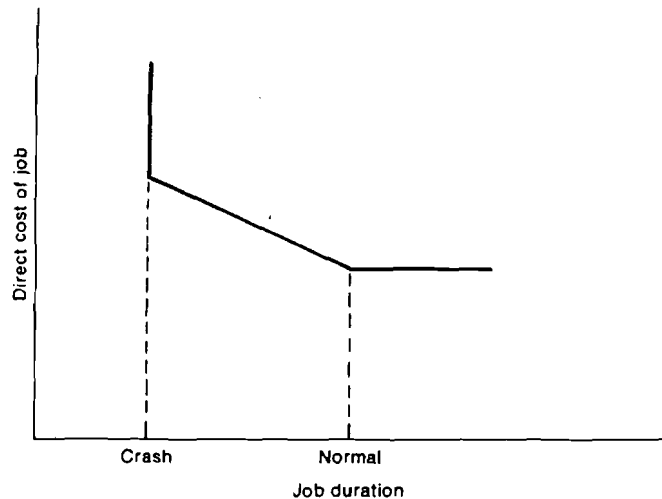
Wiest and Levy⁹ have summarized the characteristics that are essential for analysis by CPM or PERT as:

- 1 The project must consist of a well defined collection of jobs, or activities, which when completed marks the end of the project.
- 2 The activities may be started and stopped independently of each other within a given sequence.
- 3 The activities are ordered, that is, they must be performed in technological sequence.

Both CPM and PERT find the longest path or longest sequence of connected activities through the network. Such a path is called the *critical path* of the network and its length determines the duration of the project. A path is a set of nodes connected by arrows that begins at the initial node of a network and ends at its terminal node—in other words, its source and sink, respectively. With CPM, the amount of resources employed (cost) and the time needed to complete a project can be predicted within narrow ranges; they are assumed known with near certainty. Therefore, CPM addresses time-cost tradeoffs and is used where there is experience with similar work, such as in the construction industry. On the other hand, PERT is concerned with uncertainty in activity times and hence

⁹J. D. Wiest and F. K. Levy, *A Management Guide to PERT/CPM*, Prentice-Hall, Englewood Cliffs, N.J., 1977, p. 3.

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11.4

Time-cost tradeoff relationship for a typical job.

uncertainty in the project duration. It is used extensively in research and development projects.

We now take a closer look at each of the techniques.

CPM There are two kinds of costs involved with a project. The first kind are the direct costs associated with individual activities, which usually increase if the activities are expedited, shortened, or crashed. The second kind are indirect costs which decrease if the project is shortened. Figure 11.4 illustrates a possible, if simple, piecewise linear relationship between direct cost and job duration. The crash option was mentioned above. The normal option is doing the job at its normal and most efficient pace, with a lower level of resources than with the crash option. Over a certain range, the time can be reduced by using additional resources. There usually would be a minimum duration that cannot be reduced in spite of the addition of extra resources. This corresponds to the vertical portion of the line (crash). Similarly, slowing down the job will lower costs only up to a certain value below which no additional savings can be achieved. This is the horizontal portion of the line (normal). Thus, the crash option represents the *minimum possible time* to complete an activity with the added costs. The normal option provides the duration for completing the job at the *lowest direct cost*.

As the durations and costs of the activities are varied, the duration and cost of the project also vary. The CPM model specifies a

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method for finding the optimum point representing the least-cost schedule.

The model begins with the identification of the activities, followed by the drawing of the precedence diagram. Then durations and costs are assigned to the activities in the diagram. There are many methods for determining the various time and cost estimates for the project. We will describe one such method using two time-cost estimates—the normal option and the crash option—and will illustrate the procedure with a simple example.

Example 11.1 Consider a project with five activities as shown in the precedence diagram of Fig. 11.5. The parameters are as indicated in the key of the figure.

Recall that the critical path represents the longest path of the network. The critical path using the normal times is ACE with a project duration of 15 days. Using the crash times, the critical path becomes AD with a duration time of 10 days. Thus our least-cost schedule will require between 10 and 15 days, inclusive.

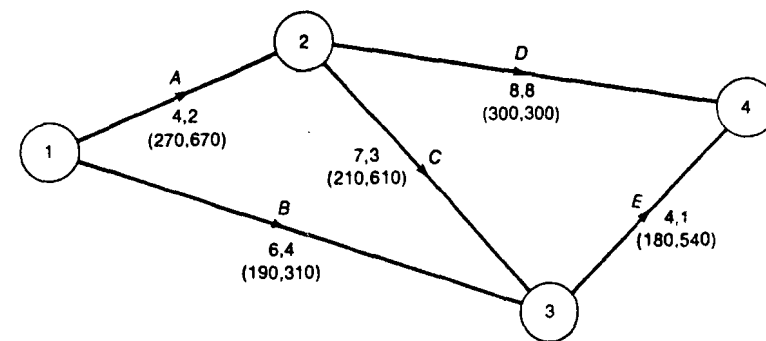
To shorten the project's duration, we begin with the normal-time critical path, ACE. Activity A, C, or E will have to be expedited. To do the crashing least expensively, we choose the activity with the lowest *activity cost slope*. The activity cost slope is defined as

$$\frac{\text{Crash cost} - \text{normal cost}}{\text{Normal time} - \text{crash time}}$$

The activity cost slopes are calculated as shown in Table 11.4

Network of CPM example.

11.5



Key: $\xrightarrow{\text{Activity name}}$
 Normal time, crashtime (days)
 [Normal cost, crash cost (\$)]

Activity Times and Costs for CPM Example

11.4	NORMAL		CRASH		ACTIVITY COST SLOPE, \$/DAY
	ACTIVITY	TIME, DAYS	COST, \$	TIME, DAYS	COST, \$
	A	4	270	2	670
	B	6	190	4	310
	C	7	210	3	610
	D	8	300	8	300
	E	4	180	1	540
			1150		2430

along with the cost and time parameters of Fig. 11.5. Notice that the activity cost slope is inapplicable to activity *D*.

From Table 11.4, we see that activity *C* has the lowest slope among the critical path activities, *A*, *C*, and *E*. So we begin with expediting *C* and proceed as follows:

15-day schedule: Normal duration for the project.

Direct cost = \$1150

14-day schedule: The least expensive way to gain 1 day is to expedite activity *C* by 1 day for \$100.

Direct cost = \$1150 + \$100 = \$1250

13-day schedule: Expedite activity *C* by another day for an additional \$100.

Direct cost = \$1250 + \$100 = \$1350

12-day schedule: Expedite activity *C* by yet another day for another \$100.

Direct cost = \$1350 + \$100 = \$1450

There are now two critical paths: *ACE* and *AD*. We cannot crash activity *C* any more unless there is an equal reduction on *AD*; in other words, both critical paths must be reduced.

11-day schedule: Activity *A* is the only one common to critical paths. It is the only activity that can be expedited, since activity *D* cannot be crashed by design and activity *E* cannot be crashed unless path *AD* is also reduced. Thus, we expedite activity *A* by 1 day at a cost of \$200.

Direct cost = \$1450 + \$200 = \$1650

10-day schedule: Expedite activity *A* by another day at an additional cost of \$200.

Direct cost = \$1650 + \$200 = \$1850

Total Costs of CPM Example

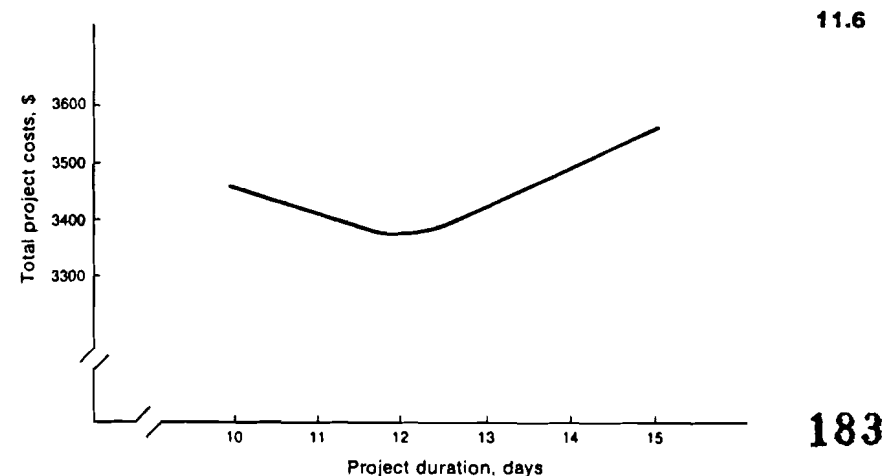
11.5	PROJECT DURATION, DAYS					
	15	14	13	12	11	10
COSTS, \$						
Direct	1150	1250	1350	1450	1650	1850
Indirect	2400	2240	2080	1920	1760	1600
Total	3550	3490	3430	3370	3410	3450

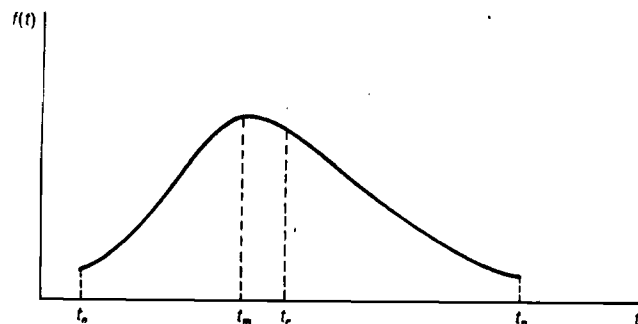
As we already noted, 10 days is the minimum duration for the project, so we cannot consider shorter periods. We now introduce the indirect costs. Suppose they amount to \$160 per day. Then the total costs for the different project durations are summarized in Table 11.5. Figure 11.6 presents a graphical illustration of the same data. In either case, we observe that the optimum or least-cost schedule is 12 days at a cost of \$3370.

PERT The PERT model considers uncertainties in time estimates of activities. As with CPM, we begin by identifying the activities and then draw the precedence diagram. Next we calculate the expected value of each activity duration as a weighted average of three time estimates. The three time estimates are:

- 1 The optimistic time t_o , with a low probability of occurring
- 2 The most likely time t_m , with the highest probability of occurring

Total costs of CPM example.





11.7

PERT beta distribution.

3 The pessimistic time t_p , also with a low probability of occurring

With PERT, we assume that t_o and t_p are about equally likely to occur and that t_m is four times as likely to occur as either t_o or t_p , on the assumption that the three time estimates describe a beta distribution,¹⁰ as illustrated in Fig. 11.7.

We then calculate t_e , the expected time for the activity; S_{t_e} , the standard deviation of t_e ; and V_{t_e} , the variance of t_e :

$$t_e = \frac{t_o + 4t_m + t_p}{6} \quad (11.1)$$

$$S_{t_e} = \frac{t_p - t_o}{6} \quad (11.2)$$

$$V_{t_e} = S_{t_e}^2 = \left(\frac{t_p - t_o}{6} \right)^2 \quad (11.3)$$

As with CPM, the critical path is identified. Since we have calculated expected activity durations, the sum of the expected durations of the critical path activities gives the expected project duration T_e . Assuming that the times for the individual activities are statistically independent, we find that V_{T_e} , the variance of T_e , is equal to the sum of the variances of the corresponding t_e . S_{T_e} , the standard deviation of T_e , is calculated as the positive square root of V_{T_e} . Both S_{T_e} and V_{T_e} give us an idea of the degree of uncertainty associated with T_e . The higher the S_{T_e} , the more likely it is that the actual project duration will differ from T_e . We will illustrate some of these concepts with an example.

¹⁰The weights are based on an approximation of the beta distribution, which is unimodal, has finite, nonnegative limits, and is not necessarily symmetrical, unlike the more popular normal distribution.

Example 11.2 Let us redraw the network of Fig. 11.5 as Fig. 11.8 with the indicated values for the time estimates. The expected times and variances are calculated using Eqs. (11.1) to (11.3). For instance, for the activity from node 1 to node 2, we have

$$t_e = \frac{5 + 4(14) + 17}{6} = 13$$

$$S_{t_e} = \frac{17 - 5}{6} = 2$$

$$V_{t_e} = S_{t_e}^2 = 4$$

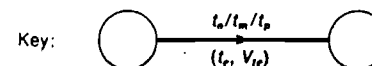
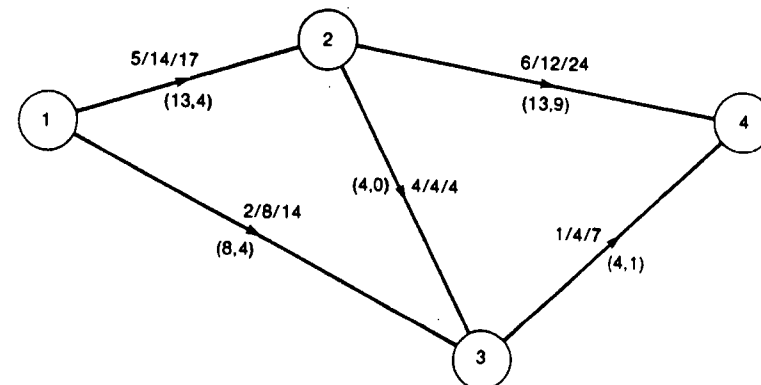
The critical path or the longest path of expected times includes activities from node 1 to node 2 and from node 2 to node 4. For this critical path, $T_e = 13 + 13 = 26$. The variance of the critical path is $V_{T_e} = 4 + 9 = 13$. Thus $S_{T_e} = \sqrt{13} = 3.6$.

After calculating the expected times for the activities and the expected project duration T_e , as well as the corresponding variances and standard deviations, we go on to compute the probability of meeting a scheduled time T . We will not go into that except to point out that the standard deviations for the activities and for the entire project provide the manager with additional information about variations in job and project times which he may find helpful.

SIMULATION AND THE CRITICALITY INDEX With the availability of the digital computer, cases in which the activity times have uncertainties can be handled readily via simulation. Activity times are randomly

Network for PERT example.

11.8



368 selected for each activity for some suitable frequency distribution by using the Monte Carlo sampling technique. After several cycles of the procedure, the average project duration and standard deviation are calculated from the simulated data.

Additionally, a count is kept on the number of simulation runs in which a given activity is on the critical path. The criticality index of an activity is the proportion of the number of runs during which it is critical to the total number of simulation runs. For instance, an activity that is critical in 2,400 out of 10,000 runs will have a criticality index of 0.24 for the project, even though it may not be critical in the one set of calculations made by the regular PERT method. The criticality index provides a measure of the degree of attention that a manager should give an activity. The higher the criticality index, the more likely an activity is to cause serious delays in project completion if not given adequate attention or control.

To conclude this section on project control, we quote from Whitehouse and Wechsler:

The control phase is needed to provide the project manager with information for managing his project. This monitoring is achieved by a comparison of the actual status of the project against the CPM or PERT schedule. The outgrowth of his comparison is a revised strategy. The monitoring phase is usually performed using a computer, although limited success can be achieved by using hand calculations. By periodically feeding the computer such data as (1) completed activities, (2) changes in the durations of activities, and (3) changes in the detailed structure of the network, the project manager obtains from the computer a monitor report illustrating the current status of the project. The monitor indicates those activities which are ahead of or behind schedule. Using new and improved data, the computer predicts when the project will be completed. It identifies critical activities and those about to become critical. The manager can thus see how the total project is progressing and can determine where maximum effort should be placed.¹¹

POSTPROJECT EVALUATION

When a major project is close to completion, one of the final tasks is the evaluation of the overall efficacy with which the resources were used and the project efforts were managed up to that point. This is called the "postproject evaluation." Considering time, cost, and performance as the three dimensions of a project, we can generally use

¹¹G. E. Whitehouse and B. L. Wechsler, *Applied Operations Research*, Wiley, New York, 1976, pp. 239 and 240.

objective, quantitative measures to evaluate the first two dimensions, but we need subjective data for the third dimension. Several approaches can be used for this purpose. Here we will present a brief summary of four methods which, taken together, provide the basis for a comprehensive process for postproject evaluation.¹²

EVALUATION OF PROJECT RECORDS

The financial records and time schedules are the best sources of objective information. A detailed study of such records shows where the cost overruns have occurred and when the delays have become critical throughout the project.

CLIENTELE ASSESSMENTS

The conduct and outcome of projects always affect a multitude of clientele, such as the project manager and his staff, the functional managers and their staffs, the engineers and scientists involved in the project, the contractors and subcontractors, and the ultimate users of the project's outputs. Questionnaires and personal interviews with these clientele provide valuable information about all aspects of the project that would be difficult to obtain from other sources. Each clientele group is asked to respond to a questionnaire specially designed to probe into the areas that particularly affect that group. The number of questions can vary from a few to several dozen, depending on the issues involved in each area. The typical areas evaluated by this method include preproject planning and organization, project management process (planning, organizing, directing, and controlling), project accomplishments, and project technology transfer. The questionnaires are generally designed with a 5- or 7-point response scale ranging from "strongly disagree" to "strongly agree" such that a statistical analysis can be performed. In addition to the questionnaires, the narrative responses obtained in personal interviews with key clientele are also analyzed for their contents. When these two are combined, an image profile for the overall performance of the project can be developed in each of the areas mentioned above.

EXPERT-PANEL EVALUATIONS

The two methods described above provide us with information about the conduct of the project but do not necessarily indicate how successful the project has been with respect to the organizational goals and objectives. This can be measured by quantifying the judgments of a group of experts who have a high degree of knowledge and understanding of the pertinent issues involved in the technical aspects

¹²See David I. Cleland and Dunder F. Kocaoglu, *Program Evaluation of the Combined Forest Pest Research and Development Program*, U.S. Department of Agriculture, January, 1981, for the details on how such a postproject evaluation might be carried out.

370 of the project. First, a panel is formed from experts who do not have a vested interest in the project. These experts are then provided with detailed information on the project goals, outputs, and the relevant criteria that can be used as the measures of effectiveness of the goals. Finally, the experts are brought together to a meeting and presented with these goals, criteria, and outputs as the hierarchical levels of project decisions. They express their subjective opinion on the relative values of each element at each level, using the hierarchical decision model approach. The meeting essentially becomes a forum for reaching consensus among the experts. After the measurements are taken and the group consensus is reached at each level, the relative values of the project outputs are expressed in terms of their contribution to the organizational objectives. This method gives us a measure of the level to which the project has fulfilled its goals and contributed to the overall objectives.

BENEFIT/COST ANALYSIS

An economic analysis of the project outcomes and their costs is called "benefit/cost analysis." This method is especially useful for evaluating engineering projects involving the public sector, such as highway, dam, and bridge projects. The basis for the B/C analysis is the comparison of the present value of benefits with the present value of the costs. Projects with high B/C ratios are considered successful (of course, a project whose benefit/cost ratio is less than or equal to 1.0 is, by definition, too costly to be accepted as a success).

The difficult aspect of the B/C analysis is the determination of the benefits, since they are hard to define and hard to measure. One of the best methods for determining the benefits is to use a panel of experts. Once the benefits are defined and the costs delineated as described in the first method above, the analysis is performed using the familiar present value calculations.¹³

These four methods can be used by themselves or in combination with each other for postproject evaluation purposes. It may be sufficient to use only one or two of them for simpler projects. However, for the more complex projects, an integration of the four is usually needed.

SUMMARY

Projects need constant monitoring as they go through their life cycle. At the initial phase the prospective projects are evaluated for their economic, technical, and market feasibility in order to select the most promising ones. This is called the *preproject evaluation*.

¹³Present-value concept is discussed in any good book on engineering economy.

Once a project is under way, its day-to-day operation in terms of time, cost, and performance is evaluated via project control techniques and project review meetings. These activities constitute the *ongoing project evaluation*.

Finally, as the project winds down, a careful assessment is necessary to see what happened in it, how well it was managed along the time, cost, and performance dimensions, and what it produced throughout its life cycle. This activity is called *postproject evaluation*.

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DISCUSSION QUESTIONS

- 1 The authors state that projects are building blocks of an engineering organization's strategy to achieve overall goals and objectives. Why is this so?
- 2 The evaluation of a project can be done at least three times during the project's life. What are these times?
- 3 Why does the engineering manager need a rational methodology for the selection of engineering projects?
- 4 Project selection methodologies range from simple to complex. What are the different methodologies in these categories?
- 5 What is the advantage of using the simple rank-ordering method?
- 6 Why is the development of criteria for the evaluation of projects so important?
- 7 Who should develop the criteria for the evaluation of projects?
- 8 What is the essence of the hierarchical model in the evaluation of projects?
- 9 What are the basic questions that should be addressed during an ongoing project evaluation process?
- 10 How can the Gantt chart be used in project evaluation?
- 11 An integral part of both CPM and PERT is the use of networks. Demonstrate that you understand the use of networks.
- 12 What are some of the techniques that can be used for postproject evaluation?

KEY QUESTIONS FOR THE ENGINEERING MANAGER

- 1 What is the policy in this organization concerning the evaluation of ongoing projects?
- 2 Has provision been made for relating project evaluation to the strategic planning in the organization?

- 372 3 Who makes the decisions on the selection of a project in this engineering organization? Is this the right person to make the decision?
- 4 What are the techniques being used in preproject evaluation in this organization? Can these techniques be improved?
- 5 Considering the range of alternatives available in project selection methodologies, which are best suited to the cultural ambience in this organization?
- 6 Has somebody been identified as the focal point for the development of project selection methodologies in the organization?
- 7 Do the engineering project managers understand the various methodologies that are available for the selection of projects?
- 8 How are projects evaluated in this organization? Is there room for improvement in this evaluation process?
- 9 Do the technical people in this organization understand the advantages (and limitations) of using the Gantt chart as a project evaluation technique?
- 10 What is the current method for doing a postproject evaluation? Does this evaluation take into consideration the strategic objectives of the organization?
- 11 Who are the clientele of the key engineering projects currently being conducted in this organization?
- 12 Is there any opportunity for the application of expert panel evaluations in the projects currently being managed in this organization?

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